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A BIOMECHANICAL COMPARISON BETWEEN A BASEBALL PITCH AND A FIRST SERVE IN TENNIS

By

Marc A. Keller

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

Moheb A. Ghali, Dean of the Graduate School

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MASTER'S THESIS

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Marc Keller
December 9, 2012

A BIOMECHANICAL COMPARISON BETWEEN A BASEBALL PITCH AND A FIRST SERVE IN TENNIS

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Marc A. Keller
December, 2012

Abstract

Tennis and baseball are popular sports that have similar overhand motions, but result in two different final velocities. The two sports also have different risk of injuries. The study was conducted to compare the angular kinematics of both motions. One volunteer participated in the study. Subject's shoulder and elbow angular position and velocities throughout a first serve in tennis and a fastball pitch in baseball were recorded with the use of a camera-based motion analysis system. Both the Cardan sequence (XYZ) and Euler sequence (ZYX) were used to analyze the motions within Visual 3D. A descriptive analysis was used to compare the two actions at the shoulder and elbow for angular position and angular velocity. Both sports showed similar overhead motions with regard to elbow and shoulder position. Overall, elbow angular velocity was larger in tennis than in the fastball pitch. Tennis also had a general higher angular velocity value in the shoulder. Angular velocity differences at the shoulder and elbow between a fastball pitch in baseball and first serve in tennis warrant further examination for injury risk assessment.

Keywords: baseball pitch; tennis serve; angular velocity; joint position; shoulder;

elbow

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Chapter I

The Problem and its Scope

Introduction

Baseball and tennis are popular sports throughout the world. The two sports have very similar overhand motions but yield two vastly different final velocities. Tennis serves can be measured at close to 150 miles per hour, while a baseball fastball reaches a lesser value of 103 miles per hour. The additional length that the tennis racket adds to the lever arm is a possible reason for the different velocities. Other kinematic differences may also be present, such as the angle of contact/release and projectile weight. Differences in kinematics may also bring with them differences in injury rates between the two activities.

Tennis players are continually being challenged to increase their serve velocity in an attempt to dominate their opponent (Fleisig, Nicholls, Elliott, & Escamilla, 2003). A first serve in tennis is meant to be an intense serve and is performed at the beginning of each point. The athlete attempts to create an un-returnable serve by increasing the velocity. If the first serve lands out of the service box, then the server will relax to a slower serve in order to maintain control and lessen the chance of allowing the opponent an easy point by faulting twice.

Baseball pitchers have a variety of pitches in their arsenal. Sliders, curve balls, change-ups and knuckleballs are different pitches that can cause a hitter to miss-hit or strike. However, the fastball is a more controlled pitch that is highly effective due to its high velocity. While the ability to pitch at high velocities is extremely desirable for athletes, it is extremely difficult to achieve (Werner, Suri, Guido, Meister, & Jones, 2008). Due to the

complex nature of pitching mechanics, ball speed cannot be easily explained through pitching mechanics (Werner et al., 2008).

Multiple studies have examined the kinematics of a baseball throw and tennis serve individually (Dun, Kingsley, Fleisig, Loftice, & Andrews, 2008; Elliott, Fleisig, Nicholls, & Escamilla, 2003; Gordon & Dapena, 2006; Osbahr, Cannon, & Speer, 2002; Werner, Gill, Murray, Cook, & Hawkins, 2001; Werner, Murray, Hawkins, & Gill, 2002; Werner et al., 2008). However, studies comparing the two actions simultaneously are less common (Atwater 1979; Lee, 1995). Due to the small amount of research looking at the shoulder and elbow of both an overhand baseball pitch and a first serve in tennis, this study was designed to compare the angular kinematics of both motions.

Purpose of Study

The purpose of this study was to examine minimum and maximum values of the shoulder and elbow. The values include angular positions and velocities throughout a first serve in tennis and a fastball pitch in baseball.

Hypothesis

Hypothesis testing was not conducted in this study; however, the angular positions are expected to be similar in the sports, while angular velocities are expected to be greater in the baseball pitch than the tennis serve.

Significance of Study

There is a minimal amount of research comparing an overhand baseball pitch and a first serve in tennis. The significance of this study is to add insight into the differences or similarities between a baseball pitch and tennis serve regarding joint angles and velocities at

the elbow and the shoulder in order to review the risk of injury between the sports.

Limitations of Study

1. The subject neither pitched nor served a ball, but instead mimicked the appropriate action. The subject performing the tennis serve performed the motion using a tennis racquet in each of the trials. Using a baseball or tennis ball, or even a ball that is the same size but a lighter weight, may have had an effect on performance mechanics (Fleisig et al., 2006).
2. The skin mounted motion sensors do not necessarily follow the exact motions of the underlying bones. Reliance upon surface markers might have led to errors in the computed angular velocity values and segment orientations (Gordon & Dapena, 2006).
3. The study took place in a lab and was not a real life pitching or serving situation. The subject may have altered his throw/swing due to the confined space or lack of effort (Escamilla, Fleisig, Zheng, Barrentine, & Andrews, 2001).
4. The study of a single subject may limit the ability to detect real differences between the two motions.
5. The lack of random selection from the population will limit the application of the results to other populations (Fleisig et al., 2006; Girard, Micallef, & Millet, 2005).
6. The subject participated in the study during his offseason, potentially lessening his maximal effort due to not being in peak condition or fear of injury (Osborne et al., 2002).

Definition of Terms

Abduct: To move away from midline or center of the body (Marieb, 2004)

Adduct: To move toward the center of the body (Marieb, 2004).

Bursa: A fluid-filled sac found within the body to reduce friction at joints (Hamill & Knutzen, 2009).

Concentric contraction: Shortening of a muscle against resistance (Prentice, 2003).

Distal: Farthest from the trunk (Prentice, 2003).

Eccentric muscle action: Lengthening of a muscle against resistance (Prentice, 2003).

Extension: Increasing a joint angle (Marieb, 2004).

External rotation: Anterior surface moves away from the midline and posterior surface of the arm runs toward the midline (Hamill & Knutzen, 2009).

Flexion: Decreasing an angle of a joint (Marieb, 2004).

Frontal plane: Passes from one side of the body to the other, creating a front and back side of the body (Behnke, 2006).

Horizontal abduction: A transverse plane motion that is a combination of extension and abduction of the arm (Hamill & Knutzen, 2009).

Horizontal adduction: A transverse plane motion that is a combination of flexion and adduction of the arm (Hamill & Knutzen, 2009).

Horizontal (or transverse) plane: Passes through the body horizontally to create top and bottom segments of the body (Behnke, 2006).

Inferior: Directional reference meaning below (Martini, Timmons, & Tallitsch, 2003).

Internal rotation: A transverse plane motion where an anterior surface of the arm moves toward the midline of the body, while the posterior surface moves away from the midline (Hamill & Knutzen, 2009).

Kinetic chain: In a weight-bearing position, the kinetic chain involves the transmission of forces in a proximal-to-distal sequence (Girard et al., 2005; Prentice, 2003).

Kinetic energy: The energy resulting from motion (Hamill & Knutzen, 2009).

Lateral: Further from midline of the body (Marieb, 2004).

Medial: Closer to the midline of the body (Marieb, 2004).

Potential energy: The capacity to do work because of position (Hamill & Knutzen, 2009).

Pronation: A transverse plane motion that consists of movement of the forearm at the radioulnar joint where, from an anatomical position, the palm of the hand travels from an anterior-facing position to a posterior-facing position (Marieb, 2004).

Proximal: Nearest to the midline (Prentice, 2003).

Sagittal plane: Passes from the front through the back of the body, creating right and left sides of the body (Behnke, 2006).

Stages of a Baseball Throw: A baseball throw consists of four stages; windup, cocking, acceleration, and follow through (Altcheck & Dines).

Stages of a Tennis Serve: A tennis serve consists of six stages; windup, early cocking, late cocking, early follow through and late follow through (Seeley, Uhl, McCrory, McGinn, Kibler, & Shapiro, 2008).

Stretch-shortening cycle: An eccentric muscle action immediately followed by a concentric action in quick order (Hamill & Knutzen, 2009). Superior: Directional reference meaning above (Martini et al., 2003).

Supination: A transverse plane motion that consists of movement of the forearm at the radioulnar joint where the palm of the hand faces anteriorly (Marieb, 2004).

Radial deviation: A frontal plane motion that is movement at the wrist where displacement occurs toward the radius (Prentice, 2003).

Ulnar deviation: A frontal plane motion that is movement at the wrist where displacement occurs toward the ulna (Prentice, 2003).

Varus force: A force applied to the medial side of the elbow (Prentice, 2003).

Valgus force: A force applied to the lateral side of the elbow (Prentice, 2003).

Chapter II

Review of Literature

Introduction

The shoulder is a very complex joint that is commonly injured during overhand motions. During these movements, injury to the glenohumeral joint is commonly due to the high stresses that are put on the shoulder by large forces (Braun, Kokmeyer, & Millett, 2009). The elbow is also at risk for injury due to the large valgus stress that occurs during overhead motions (Borak, 2009). Baseball and tennis share similar overhand motions that prove to be essential for each sport (Gainor, Piotrowski, Puhl, Allen, & Hagen, 1980) with tennis athletes being able to achieve much higher final velocities.

Baseball is a popular high school sport in the United States as well as a common method for adolescents to maintain their physical fitness and a healthy lifestyle (Collins & Comstock, 2008). Participation in sport can result in multiple shoulder and elbow injuries, leading to time loss from competition, even in athletes who were physically fit (Dick et al., 2007; McFarland & Wasik, 1998). Shoulder injuries that were not acute injuries (i.e. dislocations and/or sprains) accounted for 22.1% of the severe injuries resulting in ten or more days of activity time lost in Division I, Division II and Division III baseball athletes between 1988 and 2004 (Dick et al., 2007). Overall, it has been shown that shoulder injuries accounted for 24% of all baseball injuries during the season (McFarland & Wasik, 1998).

There is a fine line between a normal amount of laxity that allows overhead athletes to propel objects at high speeds and an abnormal amount of laxity that potentially leads to injuries (Altchek & Dines, 1995). Tennis and baseball athletes have a different risk of injury. Despite tennis athlete's ability to reach higher speeds, they seem to be less frequently injured,

although there is little research comparing injury rate of the two sports. Baseball pitchers can potentially reduce their risk of injury by participating in an active and appropriate preseason conditioning program (Dick et al., 2007). It is important to understand the possible mechanisms of injury related to the shoulder and elbow in order to prevent related injuries.

Positions, Planes, and Motions

Angular positions and angular velocities of the shoulder and elbow that occurred during a fastball pitch in baseball and a first serve in tennis were examined in this study. Within the reference frame for the pitch and tennis serve (Figure 2) exists three axes of rotation as well as three cardinal planes. The sagittal plane divides the body into right and left sections (Behnke, 2006). The transverse plane divides the body into top and bottom sections, while the frontal plane divides the body into anterior and posterior sections (Behnke, 2006). Within each plane, a series of motions take place. In the sagittal plane, flexion and extension of the shoulder and elbow joint occur (Hamill & Knutzen, 2009). In the frontal plane, abduction and adduction of the shoulder joint occurs (Hamill & Knutzen, 2009). Horizontal abduction and adduction of the shoulder, internal and external rotation of the shoulder, as well as pronation and supination of the forearm, occurs in the transverse plane (Hamill & Knutzen, 2009). Bones rotate around a joint in their plane perpendicular to an axis of rotation (Behnke, 2006). The axes of rotation are the y-axis, which represents an anteroposterior axis of rotation, the x-axis which represents a mediolateral axis of rotation, and the z-axis which represents a vertical axis of rotation. Motions that occurs around the anteroposterior axis of rotation at the shoulder are abduction and adduction (Hamill & Knutzen, 2009). About the mediolateral axis of rotation, flexion and extension of the shoulder and elbow occur (Hamill & Knutzen, 2009). The vertical axis of rotation serves as

a point for internal and external rotation, as well as horizontal abduction and adduction at the shoulder and supination and pronation of the elbow (Hamill & Knutzen, 2009).

Functional Anatomy of the Shoulder Complex

The shoulder complex is one of the most complicated joints in the body. Movement at the shoulder involves a series of complex movements and actions between four separate joints: the scapulothoracic, sternoclavicular, acromioclavicular, and glenohumeral joints (Hamill & Knutzen, 2009). The glenohumeral joint is a ball-in-socket joint with the glenoid fossa acting as the socket and the head of the humerus serving as the ball portion (Behnke, 2006). The glenoid fossa serves as an attachment site for the glenoid labrum (McLeod, 1986). The labrum is a fibrous mass and is often a site of injury in overhand throwing athletes (McLeod, 1986). The labrum adds stability to the shoulder joint by increasing the depth of the glenoid fossa (Marieb, 2004). Three bones play essential roles in the effectiveness of the glenohumeral joint which are the scapula, humerus, and clavicle (Marieb, 2004).

Skeletal Structures. The scapula plays a vital role in shoulder anatomy and stability throughout the throwing motion. During rotational movements such as a baseball pitch or hitting a tennis serve, the glenoid fossa of the scapula only allows for minimal stabilization of the joint (Kibler, 1991). Because of the glenoid fossa's shallow surface, little bony stability is created, which leaves the shoulder to rely on soft tissue structures for restriction and stabilization (Kibler, 1991). The glenoid fossa acts as the pivot for most motions of the glenohumeral joint, including throwing (Kibler, 1991). In addition to serving as a pivot, the scapula provides space for muscular attachments (Kibler, 1991; Marieb, 2004). This aspect of the shoulder allows for much of the soft tissue stabilization that is crucial for functional

movement of the shoulder (Kibler, 1991). Another major role of the scapula during the throwing motion is retraction and protraction over the thoracic wall which directly affects speed (Kibler, 1991). Retraction of the scapula toward the midline is at its greatest during the wind up and cocking phases (Kibler, 1991). This retraction allows for a maximal storage of energy in the anterior muscles, which consequentially provides an accelerating force in the initiation of a pitch (Kibler, 1991). This allows for the humerus to abduct and externally rotate until the end of the maximum rotation phase, at which point the arm can produce maximum force (Kibler, 1991).

Muscles Acting on the Shoulder. In order for efficient movement and performance to occur, coordinated muscle firing patterns are crucial (Kibler, 1991). The trapezius, rhomboids, and serratus anterior muscles work in conjunction with the rotator cuff muscles. They attach on the scapula and aid in its stabilization (Kibler, 1991). The trapezius muscle may also act on the scapula to aid in elevation, retraction, depression and upward rotation (Martini et al., 2003). The rhomboids adduct the scapula and also aid in downward rotation of the bone (Martini et al., 2003). The serratus anterior protracts the shoulder, as well as aids in upward rotation, which allows the glenoid fossa of the scapula to move superiorly (Martini et al., 2003). Like its name suggests, the levator scapula muscle elevates the scapula (Martini et al., 2003).

The rotator cuff is a group of muscles that are active during an overhead motion (Kibler, 1991). It is made up of four muscles: supraspinatus, infraspinatus, teres minor, and subscapularis (Behnke, 2006; De Maeseneer et al., 2006; Hoppenfeld, 1976; Kibler, 1991; Marieb, 2004; McLeod & Andrews, 1986). The rotator cuff muscles encircle the shoulder joint and blend with the articular capsule (Marieb, 2004). While the muscle group acts

together to protect the shoulder, there are specific tasks of individual muscles. During active internal rotation, the subscapularis muscle provides support for the shoulder (Braun et al., 2009; Gainor et al., 1980; Marieb, 2004; McLeod & Andrews, 1986). The infraspinatus and teres minor muscles secure the head of the humerus in the glenoid cavity (Marieb, 2004). The supraspinatus abducts the shoulder joint while stabilizing the head of the humerus in the glenoid cavity during motion (Kendall, McCreary, & Provance, 1993).

Muscle Function During Throwing. During the acceleration phase, the pectoralis major, serratus anterior, latissimus dorsi, and the subscapularis muscles exhibit high levels of activity, while the rotator cuff muscles, as well as the biceps brachii, are relatively inactive (Altchek & Dines, 1995). Forward propulsion of the upper extremity is augmented by the larger pectoralis and latissimus dorsi muscles (Jobe, Moynes, Tibone, & Perry, 1984). The rotator cuff muscles work with muscles of the trunk to achieve deceleration (Altchek & Dines, 1995). The trapezius, rhomboids, and serratus anterior muscles provide control for retraction and protraction of the scapula (Hoppenfeld, 1976). Along with upwardly rotating the scapula, the serratus anterior is a strong protractor of the scapula (Hoppenfeld, 1976). Stabilization of the shoulder is important in overhand throwing sports. The subclavius muscle aids in shoulder stability along with the supraspinatus muscle (Behnke, 2006; Marieb, 2004). The pectoralis major muscle flexes, internally rotates, and adducts the arm and is one of the major muscles active in the throwing motion (Marieb, 2004).

Functional Anatomy of the Elbow

Skeletal Structures. The humerus, ulna and radius meet to form the elbow joint (Behnke, 2006). The medial epicondyle is located on the medial side of the distal end of the humerus (Hoppenfeld, 1976). Elbow and wrist flexors insert at this bony prominence

(Marieb, 2004). The medial collateral ligament of the elbow is a commonly injured structure and is one of the basic stabilizers of the humeroulnar articulation (Hoppenfeld, 1976; Marieb, 2004). The lateral epicondyle is located on the lateral, or radial, side of the elbow joint (Behnke, 2006). It is smaller than the medial epicondyle (Hoppenfeld, 1976) and serves as an insertion point for the elbow and wrist extensor muscles (Marieb, 2004). The annular ligament is a ropelike structure that encircles the radius (Marieb, 2004).

Forearm Muscles that Stabilize and Contribute to the Upper Extremity Motion.

The muscles that act on the elbow on the posterior portion of the arm are the triceps brachii and anconeus muscles (Behnke, 2006; Hoppenfeld, 1976; Marieb, 2004). The triceps brachii and anconeus muscles are powerful elbow extensors (Behnke, 2006; Marieb, 2004). On the anterior portion of the arm are the biceps brachii, brachialis, and the brachioradialis muscles (Behnke, 2006; Hoppenfeld, 1976; Marieb, 2004). The biceps brachii flexes the elbow and aids in forearm supination (Behnke, 2006; Marieb, 2004). Both the brachialis and brachioradialis muscles aid in elbow flexion.

Elbow Motion During Throwing. The elbow sits in a flexed position at the beginning of the wind-up phase (Gainor et al., 1980). At the peak portion of wind-up, the triceps muscle contracts, taking the elbow into extension (Gainor et al., 1980). The elbow then undergoes a large amount of flexion, up to 80°, during the cocking phase (Gainor et al., 1980). The elbow then extends during both the acceleration and follow through phases (Gainor et al., 1980). This large stress placed on the elbow occurs during the late cocking and early acceleration phases, as there is a rapid change in elbow angles and velocities (Conway, Jobe, Glousman, & Pink, 1992). This stress, combined with the horizontal

adduction at the shoulder, is also said to be a major contributor to medial collateral tears and other elbow injuries (Conway et al., 1992; Gainor et al., 1980).

Comparison of Stages in a Tennis Serve and Baseball Pitch

Due to the similarities of the pitch and serving motion, the four major stages of pitching (wind-up, cocking, acceleration, and follow-through) (Altchek & Dines, 1995; Braatz & Gogia, 1987; Jobe et al., 1984) are commonly used to describe the stages of the tennis serve (Atwater, 1979; Morris, Jobe, Perry, Pink, & Healy, 1989; Ryu, McCormick, Jobe, Moynes, & Antonelli, 1988; Seeley et al., 2008). The differences of muscular timing patterns (Groppel & Roetert, 1992) and joint movement between tennis players and baseball pitchers may cause stresses to develop in diverse manners (Lee, 1995). This could result in various overuse injuries that are distinctive to each sport.

Stage one: Wind-up. There is little difference between the two sports in the dominant arm during the wind-up phase (Lee, 1995). This phase is comprised of concentric muscle actions that are within a normal range of motion and are controlled, placing the shoulder at a lower risk for injury (Lee, 1995). Despite similarities in the upper extremity during the wind-up phase, lower extremity motions are different between the two actions (Lee, 1995). In order to develop anterior momentum, the pitcher initially steps back on his right, or non-lead, leg (Braatz & Gogia, 1987). This allows for the lead leg to prepare for a forward stride by flexing at the knee and hip (Braatz & Gogia, 1987). The lifting of the lead leg allows for the kinetic chain to begin by placing the trunk in a coiled position (Lee, 1995). The rules of tennis, however, limit the amount of forward movement a tennis player can create (Lee, 1995). Anterior movement of the left foot past the baseline on the court is known as a foot fault, thereby penalizing the athlete (Lee, 1995). The tennis player must

keep both feet on the ground during this motion in order to avoid penalty (Lee, 1995). The wind-up stage of the tennis serve begins with shoulder in line with the direction of the serve and ends with ball release from the left hand with the toss (Lee, 1995; Ryu et al., 1988). During the late portion of the wind-up stage, the lower trunk and extremities prepare for the explosive build-up of power during the cocking stage (Chow, Shim, & Lim, 2003).

Stage two: Cocking. The cocking stage can be differentiated from the other phases of the throw by the athlete's ramping up of power (Lee, 1995). The cocking phase is sometimes divided into early and late sub-phases (Lee, 1995). Generally, the build-up of power in the lower extremities occurs during early cocking, while a build-up of power in the upper extremities takes place during the late cocking phase (Lee, 1995). As the pitcher drives his body forward and initiates left trunk rotation, the early cocking phase occurs (Lee, 1995). Once the shoulder reaches maximum external rotation and the lead foot makes contact with the ground, the late cocking phase begins (Lee, 1995). In tennis, cocking begins with ball release from the left hand and ends with the right shoulder in maximal external rotation (Morris et al., 1989). Morris et al. (1989) divided the cocking phase into a percentage of the motion, with early cocking consisting of the first 75% of the phase, while late cocking is the remaining 25%.

Both sports demonstrate similar biomechanics in the dominant shoulder of the athletes (Lee, 1995). The muscles of the shoulder are performing concentric actions while the shoulder is transitioning into abduction and external rotation (Lee, 1995). During this motion, the shoulder and elbow joints can easily be controlled and are within a normal range of motion (Lee, 1995). In the pitcher, the rotated trunk begins to uncoil (Lee, 1995). Anterior ground reaction forces in the lower extremity are maximized by utilizing a long

forward stride during the pitching motion (Lee, 1995). Due to the baseline, the tennis player's anterior movement is significantly limited (Lee, 1995). Early in the closed kinetic chain, lower extremity eccentric muscle actions are initiated (Lee, 1995). By having successful activation in the lower extremity of the stretch-shortening cycle, the tennis and baseball players are able to construct a solid foundation of power (Lee, 1995).

The shoulder joint of both athletes reaches full external rotation and 90° of abduction at the end of the late cocking phase (Lee, 1995). The anterior capsule of the shoulder, along with its structures, is stretched to its physiological limit during this point of the motion (Lee, 1995). At the late cocking stage, the position of the glenohumeral joint strongly resembles a closed packed position, with the shoulder in abduction and extreme external rotation (Williams, Warwick, Dyson, & Bannister, 1989). A closed packed position offers a maximum amount of stability to that specific joint (Williams et al., 1989). In this position the ligaments are stretched tightly and the surfaces of the joint are most congruent, creating static stability (Lee, 1995). This stability is compromised, however, due to the dynamic nature of the two motions during the late cocking phase (Lee, 1995). To add dynamic stability, internal rotators such as the latissimus dorsi and pectoralis major become active (Jobe et al., 1984; Ryu et al., 1988). The stretch-shortening cycle activated by end-range eccentric actions occurring in the late cocking phase generates power produced by the internal rotators of the shoulder (Lee, 1995).

Both the baseball pitcher and the tennis player undergo a strong concentrically driven movement that began in a fully rotated position into trunk hyperextension, non-dominant side flexion, and rotation to the non-dominant side (Lee, 1995). The glenohumeral joint of the dominant arm maintains its position due in large to the trunk motion of rotation in both

athletes (Atwater, 1979). Ideal static and dynamic stability is maintained through trunk rotation (Lee, 1995). If the joint is taken out of its closed packed position, static stability may be weakened, which places joint structures at an increased risk of injuries (Lee, 1995). Dynamic stability may also be weakened as the shoulder moves into abduction (Bradley & Tibone, 1991). If shoulder abduction range of motion increases, the risk of the acromion becoming impinged onto the underlying soft tissue structures also increases (Lee, 1995). While injuries can occur at any point in the kinetic chain, the shoulder is extremely at risk in tennis players and baseball pitchers (Lee, 1995). The late cocking stage places the glenohumeral joint in extreme ranges of motion placing the shoulder at a high risk of injury (Lee, 1995). Both dynamic and static joint structures are loaded to their physiological limits from internal and external forces (Lee, 1995). The late cocking stage, therefore, is associated with several upper extremity injuries, including joint instability and muscle imbalances (Lee, 1995).

Power generated from the athlete during this stage is often the mechanism of shoulder injuries. In an attempt to maximize power, an athlete may take the joint to extreme ranges of motion which can stretch joint capsules and ligaments (Lee, 1995). Contractile injuries may occur during the stretch-shortening cycle due to eccentric overload (Lee, 1995). Injuries relating to dynamic joint instability or static joint instability are most commonly seen during the cocking phase (Bradley & Tibone, 1991). Eccentric muscle overload may lead to dynamic joint instability injuries (Lee, 1995). The last stage of power build up necessary for the acceleration phase is produced by end range actions of the horizontal adductor and internal rotators of the shoulder (Ryu et al., 1988). In either sport, the late cocking stage

increases an athlete's risk of injury due to repetitive, eccentric actions of the stretched internal rotators (Lee, 1995).

There are two important factors that contribute to an athlete's success in generating power (Lee, 1995). The first factor depends on the ability of the athlete to stimulate the specific muscle groups stretch-shortening cycle (Lee, 1995). The second factor regards coordinated muscle activation patterns that generate power in the lower and upper extremities in a sequential manner, creating the dynamic kinetic chain (Lee, 1995). In the baseball pitch, the sequence of events building power begins at the pelvis, travels through the upper trunk, upper arm, and, as a unit, ending with the forearm and hand (Atwater, 1979). To maximize power build-up, coordination within the dynamic kinetic chain from one segment to the next should be fluid (Lee, 1995).

Stage three: Acceleration. The release of power occurs during the acceleration stage (Lee, 1995). During the cocking stage forces are generated through the dynamic kinetic chain and these forces are released through the ball during the acceleration phase (Lee, 1995). The acceleration phase begins with internal rotation of the dominant arm and concludes at ball release (Braatz & Gogia, 1987; Jobe, Tibone, Perry, & Moynes, 1983; Pappas, Zawacki, & Sullivan, 1985; Sabick, Torry, Kim, & Hawkins, 2004; Werner, Gill, Murray, Cook, & Hawkins, 2001). Like baseball, the acceleration stage of the tennis serve begins with internal rotation of the dominant arm and ends when the ball contacts the racquet (Ryu et al., 1988). Baseball pitchers and tennis players have similar muscular contractions and joint movements of the throwing arm during the acceleration stage (Lee, 1995). Concentric actions of the horizontal adductors and internal rotators, initiated during the cocking phase, allows for propulsion of the ball and the racquet during this stage (Lee, 1995).

Both the latissimus dorsi and pectoralis major provide a constant extrinsic acceleration to the active arm (Jobe et al., 1984). Proper placement of the humeral head within the glenoid fossa is maintained through muscular control of the scapula (Bradley & Tibone, 1991; Ryu et al., 1988). Dynamically controlling the upper extremity through the scapula, glenohumeral and/or elbow joints is crucial in reducing the risk of injuries for baseball and tennis athletes (Lee, 1995).

Once the lower extremities have transferred energy, they are used to stabilize the trunk and absorb energy rather than power generation (Lee, 1995). The total summation of forces generated by the dynamic chain is grouped together to create the acceleration stage (Lee, 1995). The transmission of power moves up each body segment, beginning with ground reaction forces and propelled by the stretch-shortening cycle (Lee, 1995). Power travels through the body, beginning distally in the legs, moving up to the trunk and through the dominant arm (Jobe et al., 1983; Lee, 1995). It is suggested that the greatest amount of valgus stress occurs at the elbow during the acceleration phase (Borak, 2009). Because elbow extension occurs at a rapid rate of 2,500 degrees per second, the forearm lags behind the upper position of the arm (humerus), which undergoes horizontal adduction and external rotation, creating a valgus stress during the motion (Borak, 2009). The ulnar collateral ligament is the primary source of stabilization for the elbow during this valgus force (Borak, 2009). While the ulnar collateral ligament is strong, the valgus stress during the acceleration phase can exceed 60 Newton meters (Borak, 2009). The measured strength of cadaver ulnar collateral ligaments is significantly lower than the measured valgus stress during a baseball pitch (Borak, 2009) and this large force may lead to injuries of the soft tissues.

Stage four: Follow-through. Deceleration and absorption of energy are major characteristics of the follow-through stage (Lee, 1995). The follow-through stage begins with ball release and ends with the dominant arm horizontally adducted in the pitching motion (Braatz & Gogia, 1987). In a serve, ball contact with the racquet marks the beginning of this stage and continues until the motion is completed (Morris et al., 1989). In both sports the dominant arm ends in horizontal adduction, neutral elbow extension and internal rotation to finish diagonally across the athlete's trunk during the follow-through (Altchek & Dines, 1995; Braatz & Gogia, 1987; Braun et al., 2009; Burkhart, Morgan, & Kibler, 2003; Reinold et al., 2008; Sabick et al., 2004). In both athletes, eccentric muscle actions in the lower extremity and trunk absorb forces and decelerate the body (Lee, 1995).

Shoulder decelerators of the arm are often injured during the follow-through stage due to eccentric overload, leading to posterior cuff and bicipital tendinitis (Lee, 1995). Anterior and superior translation of the humeral head may occur because of a tightened posterior joint capsule during the late cocking and acceleration stages (Harryman, Sidles, Clark, McQuade, Gibb, & Matsen, 1990).

Kinetic Chain

The act of throwing and serving requires a skilled, coordinated motion that starts at the toes, progresses through the hips, spine, arm, and into the fingers (Braun et al., 2009; Kibler, 1991; Kibler, 1998). This sequence of events is commonly referred to as the kinetic chain (Braun et al., 2009; Fleisig et al., 2003; Kibler, 1991; Kibler, 1998). Key elements in the kinetic chain are scapular timing, positioning and rotation (Braun et al., 2009). An increase in external rotation at the glenohumeral joint may contribute to the amount of energy

available within the kinetic chain allowing for greater ball velocities to be achieved (Osbaahr, Cannon, & Speer, 2002).

It is documented that the trunk continues to rotate toward home plate as the non-lead foot plants during the cocking stage of a baseball pitch (Pappas et al., 1985). At this point, the shoulder is at a position of roughly 90° abduction, 30° horizontal extension, and between 90° and 120° of external rotation (Pappas et al., 1985). This causes the glenohumeral joint to be in extreme torque, and subsequently at risk for injury (Sabick et al., 2004).

Biomechanics of the Baseball Pitch

In order for an overhand throwing athlete to be competitive, he must be able to achieve not only velocity, but precision as well (Braun et al., 2009). The ability to pitch at high speeds is desirable at any level of competition and difficult to achieve (Werner et al., 2008). Shoulder joint movements, as well as mechanics, are complex and poorly understood (Kibler, 1991). Body height, arm length, and body mass are higher in pitchers with greater velocity than lower velocity (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Werner et al., 2008). The amount of external rotation that an athlete can achieve at the shoulder most greatly affects ball velocity (Braun et al., 2009). In order to be competitive, high-level pitchers appear to have a pre-determined point of external rotation they must reach to throw high speeds (Burkhart et al., 2003). These elite pitchers know when they reach their ideal position of external rotation, called the “slot”, through proprioception (Burkhart et al., 2003).

Kinematics and Performance. Fleisig et al. (1999) reviewed pitching biomechanics among a variety of ages and ability levels. Two hundred and thirty one male baseball pitchers were analyzed for this study. Twenty-three were youth pitchers, 33 were high

school pitchers, 115 were collegiate pitchers, and the remaining 60 subjects were professional baseball pitchers. A four-camera, 200 Hz digitizing system was used to capture each subject's three fastest pitches that were within a pre-determined strike zone. Of the three fastest pitches gathered from each subject, kinematic, kinetic, and temporal data were averaged. None of the six temporal measurements exhibited significant difference but several of the kinetic parameters illustrated a significant difference between the four levels of experience. Ball velocity for the youth group was 28 ± 1 m/sec, for the high school group was 33 ± 2 m/sec, for the college pitchers 35 ± 2 m/sec, and for the professionals was 37 ± 2 m/sec (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999). The authors noticed that as the level of competition increased, so did joint forces and torques, without significant differences seen in position and temporal measures. Because of this, greater muscle strength at each higher level likely contributed to the kinetic differences. In elite pitchers, torques and forces generated during the cocking and acceleration stages of throwing produce higher angular velocities seen at the shoulder and elbow. Older pitchers had longer arm segments. Most likely, these larger arm segments, in conjunction with the greater arm velocity, produce a higher ball velocity than younger pitchers.

Werner et al. (2008) hypothesized that the variability in ball speed among pitchers could be explained by a combination of variables related to pitching. Fifty-four college-aged pitchers were recruited for this study, 34 of which were right-handed while the remaining 20 pitchers were left-handed. Their mean age was 20 ± 2 years with a mean height of 182 ± 8 cm. Ten pitching trials were recorded at 240 Hz by six electronically synchronized high-speed Falcon video cameras that were attached to the wall, surrounding the pitching mound. Expert Vision software was used to track locations of 26 body landmarks for the three

fastball trials that yielded the highest speeds. Prior to ball release, maximum elbow extension angular velocity achieved a mean speed of 2251 ± 465 °/sec, while peak upper trunk rotation angular velocity averaged 1052 ± 97 °/sec. The authors found that greater elbow and stride knee flexion, shorter time from stride foot contact to maximum external rotation, less knee flexion at ball release, greater forward trunk tilt, greater shoulder external rotation, greater elbow extension, increased angular velocity of the upper trunk, and athletes who kept their weight back behind their hips were found to account for 68% of variance in ball velocity among college baseball pitchers. Werner et al. (2008) found that pitchers with a larger body mass tended to create higher ball velocity than a pitcher who weighed less. This information is to be expected, as a larger athlete would create larger forces, as a greater body mass is often indicative of superior strength.

Dun et al. (2008) looked for any differences in shoulder and elbow kinematics or ball velocity between a fastball thrown from the windup and a fastball thrown from the stretch. A pitcher is taught a specific way to pitch from the windup. He begins by standing in front of the pitching rubber on the mound, but close enough that the heels are against the rubber. The throwing hand is to hold the ball in the glove, next to the chest. The pitcher then rotates his back foot so that it is touching and parallel to the pitching rubber while still facing the batter. He lifts his front knee in front of his now rotated trunk. As he separates and abducts his arms, his front foot strides toward the batter. While the athlete rotates his trunk and arm, the front foot makes contact with the front aspect of the pitching mound. Regarding the stretch position, the pitcher begins with their back foot against the rubber, with both feet parallel to the rubber, and their front foot closer to the batter. From this position, the trunk of the pitcher is perpendicular with the path of the pitch. To execute the pitch, the pitcher lifts his

front leg and lengthens his stride. He then separates and abducts both arms to complete the pitch (Dun et al., 2008). Coaches believe that by pitching from a stretched position, the pitcher creates lower ball velocity and it can actually create more stress on the throwing arm (Dun et al., 2008). A pitcher may produce less potential and kinetic energy because during a pitch from the stretch, the lead leg does not go as high, nor does the body travel as far. The authors of this study compared the stretch and wind-up fastball among pitchers for kinetic, kinematic and temporal characteristics. Specifically they examined differences in shoulder and elbow kinetics, kinematic position at the time the front foot contacts the mound, timing from foot contact to ball release and ball velocity.

Dun and colleagues' study (2008) recruited 28 professional baseball pitchers with a mean age of 22.1 ± 2.8 years and a mean height of 191.6 ± 5.2 cm. Five pitchers were left-hand dominant, while 23 pitchers were right-handed. Twelve reflective markers were placed on each subject and were used to track the motion of each of the pitchers during maximum effort pitches. The average ball velocity from the windup was 38.5 ± 1.5 m/sec, and the average ball velocity from the stretch was 38.3 ± 1.4 m/sec. Because of the initial motion that occurs when pitching from the stretch, it is questionable whether a pitcher can achieve the same positioning at the time of foot contact as when pitching from the wind-up. A pitcher builds up potential energy during the wind-up pitch by taking the extra time to lift their front leg to a maximum height. The kinetic chain is utilized by transferring potential energy from the front leg to the throwing arm during this pitch. In comparison, the lead foot is not lifted as high during a stretch fastball pitch, therefore less potential energy is created. This decreases the amount of potential energy transferred through the kinetic chain from the lead leg to the throwing arm. However, no statistical differences in joint kinetics or timing

were found between the stretch fastball and wind-up fastball. This suggests that pitching from a stretched position is not necessarily more stressful on the shoulder and elbow than pitching from a wind-up position (Dun et al., 2008).

Fleisig et al (1999) theorize that a higher level pitcher may be at greater risk for injury because joint kinetics increase as the level of competition increases. This can only be theorized, though, as a combination of forces in soft tissues and bone represent joint kinetic values. Additionally, muscle mass and tissue strength will affect the magnitude of force necessary to create injury and likely rise as the level of competition increases (Fleisig et al., 1999). Overall, the authors suggest that pitchers should be taught proper mechanics, and, as the body develops, build appropriate strength to support the action. The authors feel that this is supported by the results which show a combination of kinetic differences, paired with a lack of temporal and position differences that varied across the levels of play (Fleisig et al., 1999).

Range of Motion in Pitchers. Osbahr et al. (2002) examined male college baseball pitchers through radiographs of their shoulders in order to determine if proximal remodeling of the humerus attributes to rotational asymmetry. The study evaluated nineteen male college baseball players. A radiograph was taken from a semi-axial view and used for evaluation across all subjects. The average age of the subjects was 19.1 years of age. Subjects had pitched for an average of 7.6 years. Twelve of the pitchers were right-handed and seven were left-handed. Passive external rotation at 0° and 90° of shoulder abduction, as well as internal rotation at 90° of shoulder abduction was measured with subjects in a supine position for the dominant and nondominant arm. Being placed in a supine position stabilized the scapulothoracic joint, thereby ensuring that there was little contribution from the

sternoclavicular, scapulothoracic and acromioclavicular joints on the motion at the shoulder. Passive range of motion was applied through a strap that was attached to a hand-held dynamometer applying a 3.5 kg load to maintain uniformity among subjects. Radiographic assessment was utilized in order to examine the retroversion of the humerus. Retroversion was measured as the angle between the epicondylar axis and the anatomic neck axis. External rotation that occurred with the dominant arm set against the body averaged $90.1 \pm 10.8^\circ$, while external rotation at 90° of shoulder abduction was $126.8 \pm 12.0^\circ$. Internal rotation at 90° of shoulder abduction measured $79.3 \pm 13.3^\circ$. Average humeral retroversion for the 19 subjects in the dominant arm was $33.2 \pm 11.4^\circ$ and the average humeral retroversion for the non-dominant arm was $23.1 \pm 9.1^\circ$. The study found a statistically significant difference between dominant and non-dominant passive glenohumeral external rotation at 0° of shoulder abduction (mean difference = 9.1°), external rotation at 90° of shoulder abduction (mean difference = 12.3°), and internal rotation at 90° of shoulder abduction (mean difference = -12.1°). The authors of the study suggest that a bony adaptation occurs with soft tissue change, thereby influencing shoulder rotation. They also found that these changes are adaptive in nature, occurring at a specific time in the pitchers growing process, and reflect either high repetition or extended exposure to throwing. However, the lack of a control group in this study leaves questions regarding natural dominant and non-dominant arm humeral retroversion (Osborne et al., 2002).

Kinematics and Risk of Injury. Werner et al. (2001) examined various parameters to quantify kinematic variables of pitching mechanics and joint loads in an attempt to clarify variables in the pitch that relate to excessive movement at the shoulder. The authors of this study defined distraction force as “equal to body weight acting on the shoulder joint as the

ball is released from the hand” (Werner et al., 2008). The force tends to pull the arm from the joint and acts along the proximal portion. After an explosive ball release, energy in the dominant throwing arm disperses quickly. During this time, distraction occurs at the shoulder and elbow joints. Professional baseball pitchers participated in this study. The athletes had a mean age of 28 ± 5 years, average height of 188 ± 5 cm and a mean weight of 90 ± 10 kg. Of the original 40 athletes, eight pitchers were left-handed, while thirty-two subjects were right-handed. Three 120-Hz cameras were used to capture the data for this study. Depending on the pitcher’s hand-dominance, cameras were placed in the right and left field bleachers and used as side views of the pitch. Above and behind home plate, a third camera was placed for all pitchers. The pitch was examined throughout the stages of the throw. Stride foot contact was used to mark the beginning of the cocking stage. Velocities and angles were calculated along with forces and torques placed on the shoulder and elbow joints. Results of the study depicted the average ball velocity at release during 40 fastballs was 40 ± 1 m/sec (89 ± 3 mph). The authors of this study concluded that five variables played the greatest role in shoulder distraction (maximum shoulder external rotation, elbow angle at ball release, elbow angle at stride foot contact, peak shoulder external rotation torque, peak shoulder abduction torque). The mean maximum shoulder external rotation angle averaged $184^\circ \pm 14^\circ$ for the 40 subjects. At stride foot contact, elbow flexion angle was $96^\circ \pm 18^\circ$. At ball release, elbow extension was within approximately 20° of full extension ($17^\circ \pm 8^\circ$). Peak shoulder external rotation torque reached an average of 111 ± 17 Nm, while peak shoulder abduction torque averaged 117 ± 34 Nm. To conclude, the authors stated that pitchers with the elbow at greater degrees of flexion at ball release appeared to incur less shoulder distraction. They also speculated that, at the end of the cocking phase,

pitchers with a more limited external rotation at the shoulder had a decreased amount of shoulder joint distraction. Also potentially associated with a reduction in shoulder distraction were lower magnitudes of external rotation and abduction torque (Werner et al., 2001). The extreme magnitudes of shoulder distraction places high demands on the rotator cuff musculature to maintain shoulder stability (Werner et al., 2001). The results of Werner et al. (2001) support that significant magnitudes of shoulder distraction occurs in pitching. The authors speculate that by considering the destructive nature of the stress to the shoulder joint, decreasing the magnitude of shoulder distraction would reduce the chance of injury to this joint.

Using the same subjects and set-up as the study performed by Werner et al. (2001), Werner et al. (2002) further investigated the relationship between valgus elbow stress, as well as the kinematic parameters, that occur during a throw. The study examined torques and forces that occurred at the elbow and shoulder joints. The authors suggest that an increase in shoulder abduction angle affected elbow valgus stress by increasing the magnitude of elbow valgus at stride foot contact. Other factors causing an increase in elbow valgus stress were: elbow flexion angle at maximum valgus stress, peak horizontal adduction angular velocity, and maximum shoulder external rotation torque. The authors found a mean ball velocity at ball release for all 40 subjects of 89 ± 3 mph. At stride foot contact, mean shoulder abduction was $190 \pm 33^\circ$ while mean peak shoulder horizontal adduction angular velocity was $933 \pm 33^\circ/\text{sec}$. Maximum external rotation torque averaged 111 ± 17 Nm for all 40 pitchers participating in this study. Elbow angle at peak valgus torque was $98 \pm 21^\circ$. This study suggests that throwers could reduce valgus stress at the elbow by reducing shoulder abduction during the acceleration phase (Werner et al., 2002).

Summary. In order for an overhand throwing athlete to be competitive, he must both precision and velocity. This can be achieved in more mature athletes, who have better mechanics and are larger in mass, as a larger athlete can produce greater force and thereby a higher velocity. In elite athletes, a bony adaptation has been shown to occur, which affects shoulder rotation. Some mechanisms, learned or adaptive, to improve ability can be harmful to the athlete. Pitchers with a greater degree of horizontal abduction and external rotation place the elbow at greater risk of injury.

Biomechanics of an Overhead Tennis Serve

The motion of a tennis serve starts with the athlete flexing both knees then extending his body upward (Fleisig et al., 2003). This movement, when combined with trunk rotation, will rotate the arm and subsequently the racquet (Fleisig et al., 2003). The tennis racquet adds mass, air resistance, and inertia, thereby lowering angular velocities at the elbow and shoulder (Fleisig, et al., 2003). However, the racquet creates an additional segment to the tennis player, which creates a higher ball velocity (Fleisig et al., 2003). Much of the forces creating high-speed elbow extension come from development along the body's kinetic chain (Gordon & Dapena, 2006).

Range of Motion in Tennis Players. One hundred professional male tennis players were recruited to participate in a study that examined the correlation between internal rotation deficits at the shoulder and shoulder pain, as well as internal rotation deficits at the hip and low back pain. Subjects ranged from 17 to 37 years old and were active with the Association of Tennis Professionals Circuit at the time of the study (Vad, Gebeh, Dines, Altchek, & Norris, 2003).

Manual goniometric range of motion measurements were taken on the non-dominant and dominant upper extremities. Measurements of the lead and non-lead hips for the lower extremity were also made with the same standard goniometric technique. The authors measured shoulder flexibility the scapula stabilized and the subject lying in a supine position. Measurements were taken for subjects by abducting the shoulder to 90° and maximally placing the glenohumeral joint in internal rotation. The flexibility of the lower extremities was also measured with subjects in a supine position. Measurements were taken with the hip in a “Fabere” maneuver (flexed, abducted, and externally rotated) (Vad et al., 2003).

Subjects were asked if they had experienced shoulder or low back pain that limited tennis performance for longer than two weeks. Then, based on their answer, they were then divided into symptomatic and asymptomatic groups. Forty-four participants experienced shoulder pain and 40 experienced low back pain. Within the lower-extremity measurements, the symptomatic low back group showed a significant deficit of 7.6° with lead-hip internal rotation when compared to the non-lead hip. While there was only a 3.2° difference for the asymptomatic group, it was a significant difference. The difference between the lead and non-lead hip with the symptomatic low back group in knee-to-floor distance was 8.6 cm, while the asymptomatic group was significantly less, at 3.2 cm. Lumbar extension was 20.3° in the asymptomatic group and 11.4° in the symptomatic group, which was also a significant difference (Vad et al., 2003).

The difference between asymptomatic and symptomatic group was not statistically significant with regard to the finger-to-floor measurement. Horizontal adduction was defined as the distance from the tip of the elbow of the adducted arm to the opposite acromion. In the symptomatic group, horizontal adduction in the dominant (D) shoulder was significantly

higher than the non-dominant (ND) shoulder ($D = 11.6 \pm 1.2$ cm, $ND = 4.4 \pm 1.3$ cm).

Horizontal adduction in the asymptomatic pain group was significantly higher in the dominant shoulder (6.5 ± 1.2 cm) than the non-dominant shoulder (4.2 ± 1.2 cm). The difference between the dominant and non-dominant shoulders in the symptomatic group with regard to the motion of horizontal adduction was 7.2 cm. The difference of the same motion in the asymptomatic group was 2.3 cm (Vad et al., 2003).

Internal rotation at 90° of abduction was found significantly higher in the non-dominant shoulder than the dominant shoulder ($D = 12.2 \pm 1.1^\circ$, $ND = 19.8 \pm 1.6^\circ$). Internal rotation was significantly lower in the dominant shoulder ($18.1 \pm 1.3^\circ$) than the non-dominant shoulder ($21.3 \pm 1.8^\circ$) for athletes with shoulder pain. There was an internal rotation deficit of 15.2° the dominant shoulder compared to the non-dominant shoulder within the symptomatic group. However, the asymptomatic group exhibited a deficit of 7.5° between shoulders (Vad et al., 2003).

The authors speculated that a decrease in efficiency of force production is caused by a decrease of shoulder internal rotation which could then lead to a higher risk of injury to the shoulder soft tissue. They further speculate that an alteration in mechanics, caused by a difference in ROM, may be a factor leading to upper extremity injuries, such as elbow injuries as well as causing shoulder pain. The study observed that excessive internal rotation deficits in the lead hip was often accompanied by the presence of low back pain. The authors suggest that repetitive forces during play resulting in capsular contractures are the cause of a decrease in internal rotation in the lead hip of tennis players. Further, an increase force transmitted to the lumbar spine was caused by a decrease of hip mobility. Therefore, a focus on increasing range of motion at the hip may potentially decrease loads placed on the spine.

The authors theorized that microtrauma and scar formation, caused by chronic stress placed on the shoulder, creates capsular contracture. This contracture further leads to a reduction of internal range of motion. They also observed low back pain highly correlates with decreased lumbar extension range of motion. The authors suggest that physical conditioning focusing on increasing shoulder and hip internal rotation range of motion be a key aspect in the treatment of low back and shoulder pain in tennis athletes (Vad et al., 2003).

Ellenbecker and colleagues (1996) examined whether differences appeared between the D and ND arm of tennis athletes. Two hundred three elite junior tennis players, ranging from 11 to 17 years of age, were measured bilaterally for active internal and external shoulder rotation, with no current injury or past history of injury within the past year. Of the subjects, 113 were males and 90 were females. Measurement was taken with a plastic, manual goniometer with scales marked at one-degree increments. Subjects were placed in a supine position with the shoulder at 90° of abduction. Subjects were asked to maximally externally rotate their shoulder from the anatomical zero rotation position of 90° of abduction. The tester provided scapulothoracic joint stabilization by applying force in a posterior direction on the coracoid and anterior aspect of the acromion. This also discouraged scapular protraction and elevation from occurring. By adding the maximum internal and external rotation ranges of motion, total shoulder rotation active range of motion was calculated. All measurements were taken for the D and ND shoulder. Male subjects showed an external rotation range of motion of $103.7 \pm 10.9^\circ$ in the D arm and $101.9 \pm 10.8^\circ$ in the ND arm. The difference was not significant. Internal rotation in males was significantly different ($p < 0.001$) between the D ($45.4 \pm 13.6^\circ$) and ND shoulder ($56.3 \pm 11.5^\circ$). Total rotation was also significantly different between the D ($149.1 \pm 18.4^\circ$) and ND

($158.2 \pm 15.9^\circ$) shoulder in males. Female external rotation range of motion was not significantly different between the D and ND arm ($105.2 \pm 10.2^\circ$ and $104.0 \pm 10.3^\circ$, respectively). Internal rotation of the females was significantly different between D and ND arm ($52.2 \pm 10.7^\circ$ and $60.3 \pm 9.8^\circ$, respectively). Total rotation in females was also significantly between the D and ND ($157.4 \pm 14.9^\circ$ and $164.4 \pm 13.6^\circ$, respectively). Results from this study demonstrate that internal rotation range of motion deficits on the dominant arm exist in this specific population of elite junior athletes. The concept of increased external rotation through the loss in internal rotation was not supported by the findings of this study, which was a decrease in total range of motion. Instead, they suggest that the dominant glenohumeral joint endures a loss of total rotation excursion. Stretching the posterior capsule and muscle groups may be a beneficial preventative conditioning program for tennis players (Ellenbecker, Roetert, Piorkowski, & Schulz, 1996).

Research has shown internal rotation deficits on the dominant arm in tennis players. It has also been shown that the decrease in rotation correlates with shoulder pain. This may be caused by injuries that occur with repetitive demands placed on the dominant shoulder of tennis players. Despite the possible reasons for the varying range of motion, physical conditioning including a stretching program can be a beneficial exercise for tennis players.

Tennis Serve Kinematics and Performance. Gordon & Dapena (2006) examined the velocity of the racquet head and the contributing factors of body segments and joints on velocity during a serve in tennis. Nine male intercollegiate tennis players, with a mean height of 1.84 ± 0.05 m, participated in this study. A total of thirteen markers were attached to each participant as well as the racquet for data collection. Three Locam motion capture cameras were used to film the serves of each participant. For the study, the authors made an

assumption that the hand and racquet rotated as a perfectly rigid unit. However, it is possible that rotation of the racquet relative to the hand contributes to the racquet speed and should be considered a possibility when contributions of racquet speed are attributed to the wrist (Gordon & Dapena, 2006). The velocity of the racquet face immediately before impact was 47.4 ± 5.4 m/s with the elbow in a position of 135° of flexion. Elbow extension speed contributed 13.5 ± 3.6 m/s to the overall racquet velocity. Wrist extension had a maximum contribution to racquet speed of 5.2 ± 1.8 m/s. Wrist rotation in the direction of ulnar deviation (4.5 ± 2.8 m/s) briefly contributed to racquet speed as the elbow increased its contribution through extension. Forearm pronation was creating a negative contribution (maximum value = -4.1 ± 1.5 m/s) at the same time ulnar deviation was attributing to the speed of the racquet. The authors suggest that the angular velocity of forearm pronation limits upward translation and outward travel of the racquet. The contribution of wrist flexion to the speed of the racquet rapidly increased as the contributions of forearm pronation and ulnar deviation decreased. This could possibly be due to forearm pronation that turns the palm of the hand forward, which also favors the replacement of ulnar deviation with wrist flexion as the main wrist contributor to racquet speed. Immediately before contact with the ball, the contribution of wrist flexion to overall racquet speed reached a large value (14.2 ± 6.6 m/s). Overall, shortly before impact the results showed that there were positive contributions of shoulder internal rotation as well as elbow extension and forearm pronation. However, the authors caution that their shoulder and elbow transverse plane motion results are not reliable when the elbow is near full extension, which occurs just before impact (Gordon & Dapena, 2006).

Three-dimensional kinematic analyses of the tennis serve was performed by Elliott et al. (2003) to compare the shoulder and elbow joint loads within 40 elite tennis players (male = 20, female = 20). Data was collected during the Olympic Games in Sydney, Australia, by videotaping singles matches performed on the main court. Video data was collected at a rate of 200 Hz, with cameras positioned approximately 20-40 m from the service area with both front and side views. Using a radar gun, ball velocity was recorded as the ball left the tennis racket. Kinematic parameters were measured from ball toss to just prior to ball impact. The researchers wrote a computer program to collect 3-D coordinate data and calculate kinetic and kinematic parameters. Inverse dynamics were used to calculate elbow and shoulder joint resultant torque and force levels. Analysis of the data found that serving speeds for male athletes (182.8 km/hr) was significantly higher than female athletes (149.3 km/hr). Overall, male players commonly recorded higher torques and forces at the shoulder and elbow joints than the female players. High levels of shoulder horizontal adduction torque (males = 107.8 ± 24.9 Nm, females = 68.8 ± 14.3 Nm), shoulder internal rotation torque (males = 71.2 ± 15.1 Nm, females = 47.8 ± 16.3 Nm) and elbow varus torque (males = 78.3 ± 12.2 Nm, females = 58.2 ± 13.1 Nm) were seen within this study. The authors suggest that by strengthening the muscles surrounding the shoulder and elbow joints through eccentric and concentric movement patterns, an athlete may help protect themselves from injury (Elliott et al., 2003).

Summary

Baseball and tennis are overhead sports that can require intense repetition depending on the duration of the event. Although delivery of a pitch or tennis serve takes a short amount of time, the repeated stress causes microtrauma both within and around the shoulder

and elbow joints. This can cause athletes of either sport to encounter chronic overuse injuries. Tennis and baseball players often experience a decrease in internal rotation range of motion accompanied by an increase in external rotation range of motion. This adaptation over several years of play affects the kinematics of both sports. Tennis and baseball utilize the kinetic chain as a way to transfer energy generated in the lower body to the upper body and impart on a ball. While the kinetic chain is occurring, there are four stages of motion that take place in both the pitch and serving motions: wind-up, cocking, acceleration, and follow-through. Despite similar movements, and repetition, between the two sports, little research has compared the joint position and velocities that occur at the shoulder and elbow joint. This study was performed to examine these variables for a more detailed comparison of these two similar motions.

Common Injuries of the Upper Extremity Associated with Upper Extremity Motion Patterns

Some factors potentially related to risk of chronic injuries among baseball pitchers are pitch types, pitch counts, and pitch mechanics (Lyman, Fleisig, Andrews, & Osinski, 2002). Depending on the situation, a pitcher may throw from several up to 100 pitches in a game, excluding warm-up and practice pitches (Lyman et al., 2002). Microtrauma, caused by repeated stress, can occur within the bursae, ligaments, and joint capsules, during the quickly delivered, one second pitch, making the shoulder and elbow vulnerable to recurring stress (Braatz & Gogia, 1987).

Risk of Upper Extremity Injury in Baseball and Tennis Athletes. Dick et al. (2007) reviewed the National Collegiate Athletic Association (NCAA) injury surveillance data for men's baseball to categorize areas of injury in athletes between 1988 and 2004.

Division I, Division II, and Division III baseball teams had participated in the annual NCAA injury surveillance system during these years. The results of this study showed that compared to other collegiate sports, college baseball has a moderately low rate of injury. However, almost 25% of injuries were considered severe and resulted in ten or more days lost from participation. Injuries were also three times more likely to occur during a game situation than practice. The upper extremity accounted for 44.6% of game and practice injuries that occurred over the sixteen-year period. In games, a shoulder strain accounted for 287 (6.5%) of injuries. Shoulder tendinitis ($n = 122$, 2.7%), dislocations ($n = 100$, 2.3%), ligament sprains ($n = 61$, 1.4%), and contusions ($n = 51$, 1.2%) also accounted for injuries that occurred during games. In practices, shoulder injuries such as muscle-tendon strains ($n = 381$, 10%), tendinitis ($n = 260$, 6.7%) dislocations ($n = 59$, 1.5%) and ligament sprains ($n = 44$, 1.1%) occurred across all divisions of play. Elbow injuries that occurred during games consisted of ligament sprains ($n = 141$, 3.2%), muscle-tendon strains ($n = 93$, 2.1%), and contusions ($n = 78$, 1.8%). Elbow tendinitis ($n = 113$, 2.9%), ligament sprains ($n = 105$, 2.7%), and muscle-tendon strains ($n = 86$, 2.2%) occurred during practices. The authors of the study found that 42% of all game injuries were caused by non-contact related mechanisms. Overall, the authors of the study suggest proper preseason conditioning to decrease the risk of injuries commonly seen in baseball pitchers (Dick et al., 2007).

Pluim, Staal, Windler, and Jayanthi (2006) methodically searched three electronic databases for published reports relating to tennis injuries beginning in 1966. Pluim and colleagues (2006) collected three analytical epidemiological studies, 28 descriptive epidemiological studies, 39 case reports and 49 laboratory studies. The search produced four principal findings. The first was that the rate of reported tennis injuries varied widely

between studies. The average amount of injuries ranged from as low as 0.05 to 2.9 injuries per player per year, found in the studies they examined. Secondly, the authors found that the lower extremities accounted for a majority of the injuries reported by the athletes. The upper extremities were the second most reported injured area, while the trunk had the least amount of the three areas. The authors found that most of the acute injuries reported within the studies happened to the lower extremities, and the chronic overuse injuries occurred in the upper extremities of the athletes. The third principal finding was the relationship between risk factors and the occurrence of injuries has not been studied very often in tennis cohort studies. Lastly, the authors of this study found that even in trials investigating preventative injury measures, none were randomized. Due to the limited research on risk factors and occurrence of injuries, Pluim and colleagues suggest that additional research needs to be conducted to study injuries, risk factors, and prevention in athletes and individuals that play tennis. (Pluim, Staal, Windler, & Jayanthi, 2006).

Shoulder Injuries. A major cause of shoulder injuries seem to be the action of throwing (McLeod & Andrews, 1986). Because of its shallow resting place against the glenoid fossa, the shoulder is an inherently unstable joint from a bony standpoint (Kibler, 1991). This naturally unstable joint can become further compromised due to the repetition and demands of overhead throwing, which may eventually cause injuries (Braun et al., 2009). While an acute, traumatic event can cause injury to an overhead athlete, such as forced dislocation or contusion, it is more likely that chronic repetition and overuse leads to the breakdown of soft tissue structures responsible for protecting the joint (Braun et al., 2009). The pitching arm is subject to chronic injury in baseball players at all levels (Gainor et al., 1980).

Labrum Tears. Labrum tears were a commonly seen injury among three sports reviewed by McLeod and Andrews (1986): baseball, tennis, and football. The combination of high speed rotational velocities created by the throwing athlete puts the articulating surfaces between the shoulder girdle and the humerus at risk for injury (McLeod & Andrews, 1986). A specific labrum tear is also referred to as a superior labrum anterior-posterior (SLAP) lesion (Braun et al., 2009). Tears of the labrum can occur acutely, or chronically, presenting more frayed (McLeod & Andrews, 1986). The lack of bony stabilization of the shoulder that allows the humerus and glenoid labrum to articulate may lead to tearing during the acceleration phase of the throwing motion (McLeod & Andrews, 1986). Off-centering of the humeral head during the deceleration phase of the throwing motion puts the labrum at risk for injury (McLeod & Andrews, 1986). In order to have an effective pitch, baseball pitchers know they need to reach maximal external rotation, despite that the increased shear forces will put them at greater risk for labral tears (Burkhart et al., 2003).

Rotator Cuff Tears. Throwing athletes are more likely to tear their rotator cuff muscles than any other athlete (McLeod & Andrews, 1986). Although the rotator cuff is made up of four muscles, McLeod and Andrews (1986) found that the subscapularis was not involved in reported rotator cuff tears. Baseball, tennis and weight lifting athletes are likely to experience tears that combine the rotator cuff and the labrum (McLeod & Andrews, 1986). Rotator cuff inflammation is one of the most common injuries of all levels of tennis players (Bylak & Hutchinson, 1998). A superior translation of the humerus can create tensile loading at certain portions of the rotator cuff (Burkhart et al., 2003). The excessive amount of external rotation that occurs during a baseball pitch can create shear and torsional overload on the posterior portion of the shoulder girdle (Burkhart et al., 2003).

Impingement Syndrome. Classic, or external, impingement is a result of the rotator cuff becoming compressed between the coracoacromial arch and the humeral head (Prentice, 2003). Rotator cuff fatigue and incorrect throwing techniques can cause the humeral head to migrate superiorly (Braun et al., 2009). This migration can increase enhance the symptoms of external impingement (Braun et al., 2009). In response to impingement, athletes should focus on rotator cuff strengthening, stretching, and scapular kinesis before trying the intervention of surgery (Braun et al., 2009).

Elbow Injuries. Hand, shoulder and elbow positioning determine the amount of stress placed on the elbow (Loftice, Fleisig, Zheng, & James, 2004). Because of the high incidence rate, elbow injuries in baseball pitchers are continually studied (Loftice et al., 2004). Specifically, the high occurrence of overuse injuries caused by excessive motion has been reviewed (Jobe, Stark, & Lombardo, 1986). Often, overuse injuries are a result of continual microtrauma due to a repetitive motion, such as pitching (Fleisig, Andrews, Dillman, & Escamilla, 1995). The tennis serve also places stress on the elbow, thereby putting it at risk for frequent injury (Loftice et al., 2004). Location of the stress and amount of tension created vary based on the technique used, and the medial and lateral collateral ligaments are particularly at risk (Loftice et al., 2004).

Medial Collateral Ligament Disruption. It is possible for athletes to sprain or tear the medial, or ulnar, collateral ligament of the elbow as a potential complication that occurs during overhead throwing activities (Mitchell, Cain & Andrews, 2008). Overhand throwing sports, such as javelin, baseball and football, are at higher risk for damage to the ulnar collateral ligament (Borak, 2009). The elbow is stabilized primarily by the anterior band of the ulnar collateral ligament (Morrey & An, 1983). When the ligament is either stretched or

torn, the joint becomes unstable (Jobe et al., 1986). An injured ligament creates pain in the elbow when undergoing a strong valgus stress, such as the stress that takes place during a pitch in baseball (Jobe et al., 1986). The greatest amount of valgus stress is placed on the elbow during the acceleration phase of the throwing motion in overhand sports (Borak, 2009).

Lateral Collateral Ligament Disruption. Wadsworth (1987) stated “tennis elbow sometimes serves as a blanket term for every pathological condition of the lateral compartment of the elbow causing pain”. While there are many theories on the pathology of lateral epicondylitis, one belief is that the injury is initiated by a microtear at the origin of the extensor carpi radialis brevis (Jobe & Ciccotti, 2004). Symptoms of tennis elbow include pain with a tight grasp or resisted motion in the wrist in the extensor forearm muscles, and tenderness to palpation over the anterior aspect of the humerus epicondyles (Gruchow & Pelletier, 1979). In tennis players, a backhand stroke often causes damage to the fibers (Rompe, Deckling & Schoellner, 2004). Also generating larger loads in the lateral aspect of the elbow are racket weight and improper grip size (Jobe & Ciccotti, 1994). Commonly, this injury is a degenerative disease (Gruchow & Pelletier, 1979) associated with repetitive overload (Bylak & Hutchinson, 1998). In order to prevent tennis elbow from developing, an athlete must have a solid understanding of the risks associate with the backhand stroke, particularly with a racket that is too large (Behnke, 2006).

Chapter III

Methods and Procedures

Introduction

The purpose of this study was to examine the maximum angular displacements and angular velocities of the shoulder and elbow joints during a first serve in tennis and a fastball pitch in baseball. A camera-based motion analysis system was used to record the two motions.

Subject Population

One college-aged male athlete was recruited for this study. The subject was proficient in both a first serve in tennis and an overhand pitch in baseball. The subject was competitive in both sports and had multiple years of experience in both sports. He was recruited from Western Washington University in Bellingham, WA, following approval of the study from the Human Subjects Review Committee. Prior to participation in the study, subject was required to read and sign a written consent form (Appendix A) and complete a health history questionnaire (Appendix B).

Design of Study

A descriptive analysis was implemented to assess kinematic differences between the baseball pitch and tennis serve, as performed by a single subject.

Data Collection Procedures

Instrumentation and Equipment. Seven ProReflex MCU240 motion capture cameras and the Qualisys Motion Capture System, sampling at 240 Hz, (Qualisys Motion Capture Systems, Inc., Gothenburg, Sweden) were used to film each of the trials performed during the study. The cameras were placed in a circular arrangement around the testing

volume in order to capture a three-dimensional representation of the motion. Each motion capture camera has a measurement range of 0.2 - 70 meters and has a horizontal field-of-view of 10 to 45 degrees. The image sensor resolutions for Qualisys cameras are 658 x 500 pixels, and the effective resolution is 20000 x 15000 subpixels.

Visual 3-D software (C-Motion, Inc., Germantown, MD) was used to calculate joint positions and velocities at the elbow and shoulder joints for comparison. Visual 3-D creates a six-degree of freedom segment model in an effort to analyze kinematic and kinetic motions. The Visual 3-D software uses exported data from Qualisys.

Measurement Techniques and Procedures.

System Calibration. Before the subject arrived, three cameras were placed on tripods and four cameras were fixed to walls oriented in a circular formation around the capture volume (Figure 1). Once the cameras were placed around the capture area, the cameras on tripods were raised to the highest point of extension to get the best view possible of the upper extremity during these motions. Camera placement and height were recorded to maintain consistency between pilot testing and the data collection session. Once the cameras were set, an L-frame was placed in the capture area to set the lab coordinate system. The global coordinate system was set by a calibration of the Qualisys system. Calibration was performed using a calibration wand in the L-frame space. The wand is a fixed length and is used within the software to calculate the motion of the markers and form a three-dimensional depiction of the motion. The calibration motion consisted of a series of twirls and shoveling motions to ensure no area was missed. Calibration was performed for 60 seconds, ensuring a

sufficient amount of time was allotted to capture the entire area.



Figure 1. The cameras were setup in a circular pattern around the capture area, with four cameras fixed to the wall and three cameras placed on tripods to ensure that the entire motion was captured. The L-frame was placed on the cart in the middle of the collection area so that it was at a height that was visible to the cameras that aimed at a tall measurement volume for the upper extremity.

Measurement Procedures. Data collection took place in the Biomechanics Laboratory at Western Washington University. The subject was informed to not participate in any activity the day of the data collection in order to avoid fatigue of the dominant arm. The subject was instructed to wear no shirt. The subject warmed up at a self-determined rate, with what he was accustomed to, until he felt able to perform a normal baseball pitch or tennis serve.

The testing environment was the same for each trial. The testing procedures were explained to the subject prior to data collection. The subject was instrumented with 24 reflective markers following the warm up (Table 1). All joint markers were placed directly on the subject's skin using double-sided adhesives rings

Table 1

Reflective Marker Placement

Joint Markers	Segment Markers
Ulnar Styloid Process	Forearm cluster (4)
Radial Head	Arm cluster (4)
Medial + Lateral Epicondyles	Seventh Cervical Vertebrae
Right + Left Acromion	Eighth Thoracic Vertebrae
Right + Left Iliac crest	Xiphoid Process
	Jugular Notch
	Right + Left Anterior Superior Iliac Spine
	Right + Left Posterior Superior Iliac Spine

Once the subject was warm and markers were in place, he was positioned in the frame of reference facing the direction of the motion. The subject was then instructed to stand in the frame of reference, facing the direction of the motion. The subject was instructed to stand perfectly still while a standing trial was performed for three seconds (Appendix C, Figure 21, 22, 23). After the standing trial was captured, the joint markers were removed and the segment markers were left on for motion capture. The subject was then instructed to perform either the baseball throw or tennis serve five times, depending on the trial. Due to a restriction in lab space, the subject was unable to actually throw a baseball or hit a tennis ball during his trials. Instead, the subject performed a maximal serve or pitch without throwing or hitting a ball. The best trial was selected and used for analysis in Visual 3-D.

Data Collection and Processing. Once the captures were complete, each marker was labeled in the Qualisys software program in accordance to its location on the body. Both the standing and motion trial were labeled in the same manner. Labeled trials were saved and exported to Visual 3-D.

Visual 3-D software was used to calculate joint positions and velocities from data exported by Qualisys Motion Capture. The data was extracted manually from Visual 3-D.

The Cardan sequence of XYZ was used to represent all three planes for the shoulder and the elbow during the tennis serve. The Cardan sequence of XYZ was used to represent the three rotations for the elbow during the overhand baseball pitch, whereas the shoulder planes for baseball were represented using the Euler sequence of ZYZ according to the recommendations of the International Shoulder Group, a subgroup of the International Society of Biomechanics (Wu et al., 2005). The ZYZ sequence of axis rotations was used in the analysis of the motions within Visual 3D. Cardan angles are ineffective in the range of abduction angles that are typically seen in the baseball pitch, and due to the difference in the degree of abduction in the frontal plane between the two conditions, the ZYZ Euler sequence was determined to be the only sequence of solving for axis rotations that would adequately represent the motions of the shoulder including horizontal adduction and horizontal abduction. However, this difference in the sequence of rotations makes the direct comparison between the tennis and baseball motions difficult, since the only shared motion that can be compared is the frontal plane motion of abduction and adduction as well as internal and external rotation. The internal and external rotation results were adjusted by 180° in order for the initial neutral position to be near 0° , instead of the output from the Euler angle sequence, which was near 200° . This adjustment renders the velocity comparison ineffective, since Euler angles are not vectors, and so the velocity cannot be calculated using a simple central difference method. The choice was to have more directly comparable position results at the cost of having comparable velocity results. The data were smoothed using a Butterworth Filter within Visual 3-D filtering with a cutoff frequency of 6 Hz.

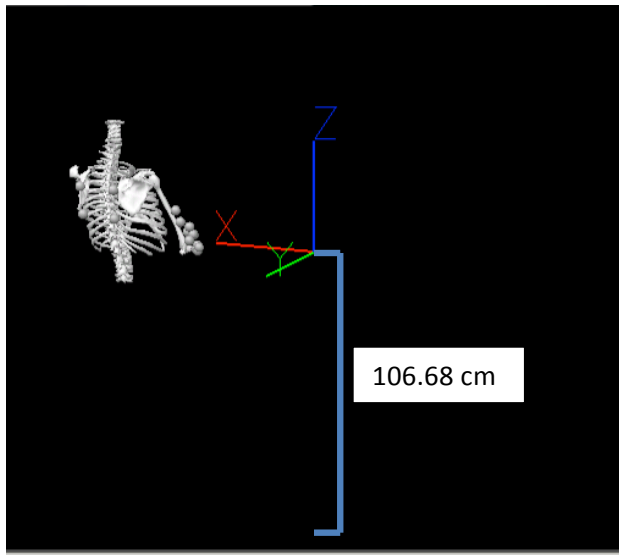


Figure 2. Axis reference frame from a posterior view. In order for the calibration frame and all upper extremity motion to be visible in the same calibrated volume, the calibration frame was placed on a cart so that it was elevated off of the ground.

Interpretation of Axis Rotations

In the sagittal plane, elbow flexion and extension are measured. Full elbow extension is labeled as 0° , whereas elbow flexion is represented by positive numbers. When the forearm goes about the sagittal axis in the frontal plane, pronation and supination occur at the elbow. An angle of 0° , or neutral, occurs during full supination, as in the anatomical position.

For the shoulder during the baseball trial, the Euler angle sequence allowed the study of: horizontal adduction/abduction, adduction/abduction, and internal/external rotation. The sagittal plane motions of flexion and extension were not available using the Euler angle sequence of rotations. In the transverse plane, with the arms elevated, a positive number represents horizontal abduction. A negative slope indicates a motion of horizontal adduction. In the frontal plane, adduction occurs with positive values and abduction occurs with negative values. A positive movement that also takes place in the transverse plane is

shoulder internal rotation. A negative movement in the same plane represents external rotation.

The Cardan sequence allowed the study of: flexion/extension, adduction/abduction, and internal/external rotation for the shoulder during the tennis serve. In the sagittal plane, shoulder flexion is portrayed through a positive movement, with extension being a negative movement. Shoulder adduction and abduction take place in the frontal plane and are represented by positive and negative movements, respectively. Lastly, in the transverse plane, shoulder internal rotation occurs with a positive movement, and external rotation a negative movement.

Data Analysis

A descriptive analysis was used to compare the two movements in all three planes of motion for both angular position and angular velocity of both the shoulder and the elbow.

Chapter IV

Results and Discussion

Subject Characteristics

One male subject was recruited for this study from Western Washington University. The age of the subject was 22 years old. His height was 180.3 cm, and his weight was 90.7 kg. The subject had seven years of experience as a baseball player and four years of experience as a tennis player.

Results

Joint Position of the Elbow. An examination of the data revealed the peak elbow flexion to be higher in the tennis serve than in the baseball pitch, while the peak extension reached a greater value in the baseball pitch than in the tennis serve (Table 2). Peak abduction was higher in tennis than in baseball. Peak adduction reached greater values in the baseball pitch than the tennis serve. With regard to peak supination, the baseball pitch reached higher angular position values than the tennis serve. The peak pronation value was greater in the tennis serve than the baseball pitch. Overall, the baseball pitch exhibited larger maximum displacement than the tennis serve in the sagittal, frontal, and transverse planes (Table 2). This suggests that during a baseball pitch, with regard to the elbow, a greater range of motion was achieved. See Figures 3, 4, and 5 for specific graphs of elbow position for baseball and tennis motions.

Table 2

Peak Elbow Angular Positions (°)

	Sagittal Plane		Frontal Plane		Transverse Plane	
	Tennis	Baseball	Tennis	Baseball	Tennis	Baseball
Maximum Displacement	99.37	97.43	43.14	56.20	25.98	57.33
Peak Flexion	132.15	122.44				
Peak Extension	32.78	25.01				
Peak Abduction			1.81	-13.48		
Peak Adduction			-41.33	-69.68		
Peak Supination					-19.16	27.94
Peak Pronation					-45.14	-39.83

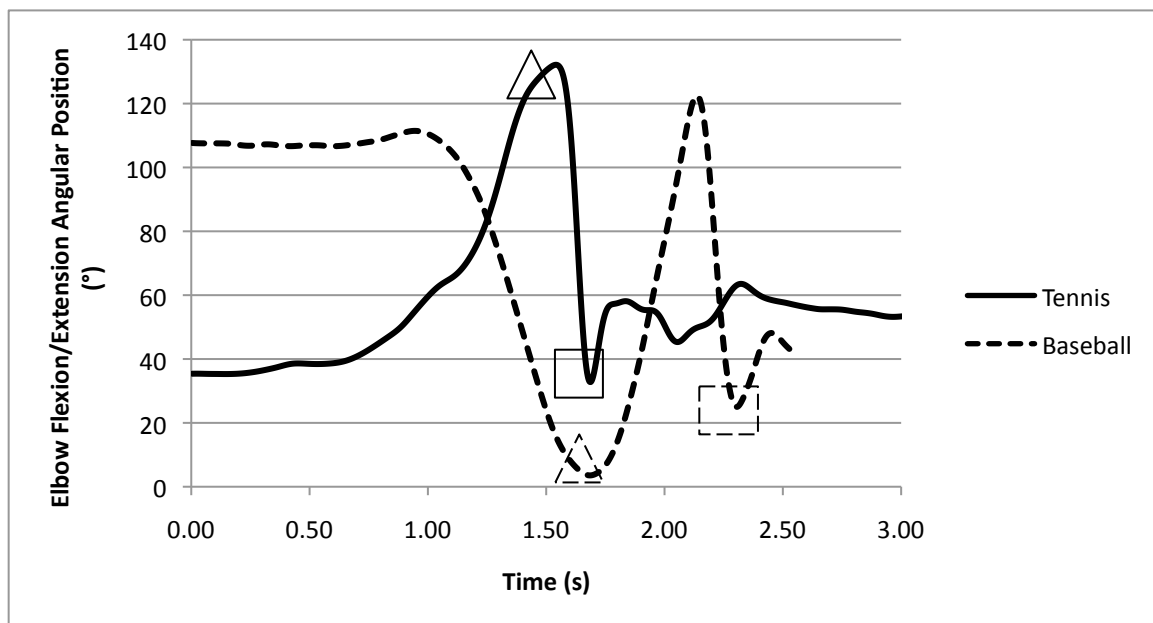


Figure 3. The graph examines the movements of flexion and extension that occur at the elbow in both actions. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. Positive slopes represent an elbow flexion motion, and negative slopes represent an elbow extension motion. The baseball pitch starts with the elbow flexed as the hands were cupped together in front of the abdomen. Then, the elbow moves into extension and experiences a rapid flexion that occurs during the acceleration phase. The tennis serve begins in a lesser flexed position than the baseball pitch, has a rapid increase in flexion during the wind-up phase and then extends during acceleration of the serve.

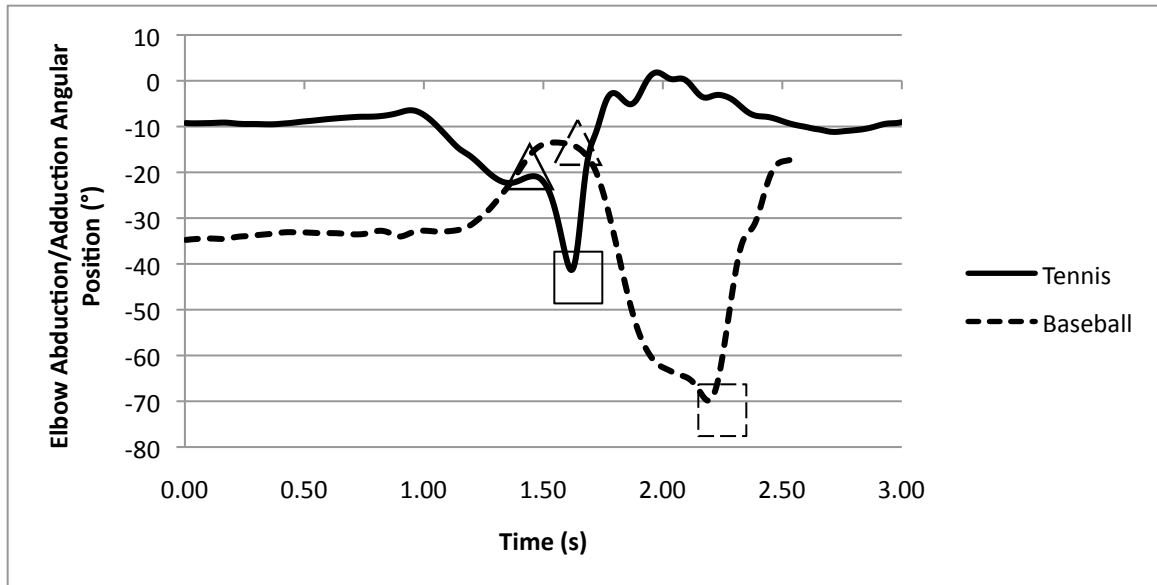


Figure 4. Adduction and abduction that occurs at the elbow can be seen in the graph above. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. The negative values represent the elbow in an abducted position. The tennis serve starts in a lesser abducted position, but increases during the wind-up, and then moves into a more abducted position when going through the acceleration phase. The baseball pitch experiences a greater abduction position throughout the entire motion, peaking during the acceleration phase. The rapid increase to adduction occurs when the pitcher is in the follow-through phase.

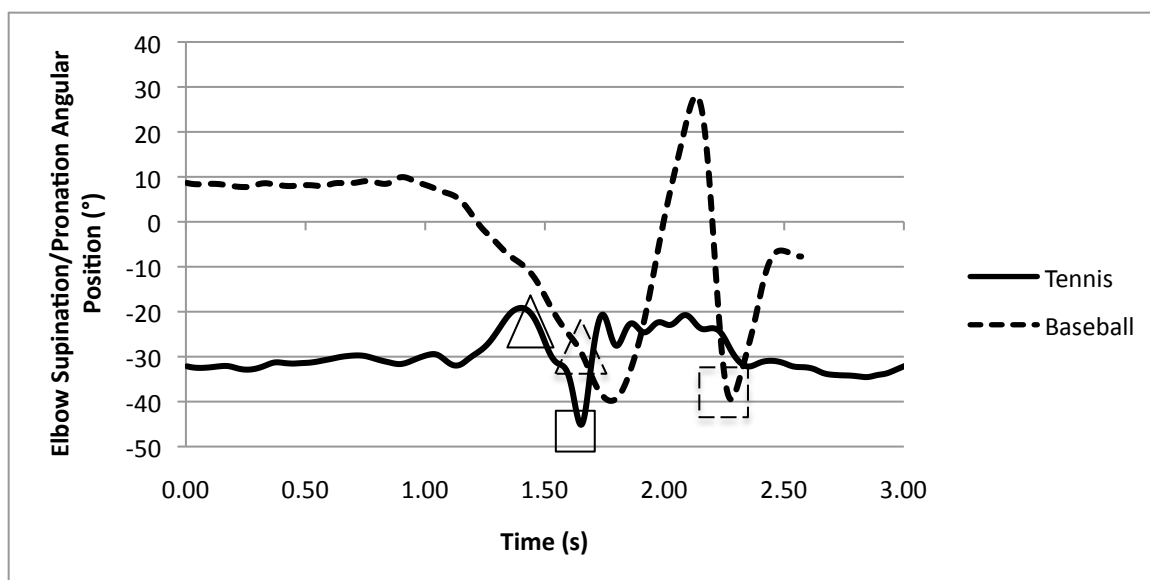


Figure 5. Pronation and supination occurring at the forearm is graphed above, comparing the action during a fast pitch in baseball and a first serve in tennis. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. The negative values represent the elbow in a supinated position, while positive reflects pronation. At the end of the wind-up phase, the forearm of the tennis serve experiences a rapid supination before the acceleration phase, where pronation occurs. The baseball pitch starts with the forearm in a semi-pronated state.

Joint Position of the Shoulder. Sagittal plane data could not be quantified for the baseball pitch because of the Euler sequence of rotations that is necessary to process the motion of the shoulder in the ranges of abduction seen in the baseball pitch. Instead, peak horizontal adduction and peak horizontal abduction were examined in the transverse plane at the shoulder and can be seen in Figure 7. In the frontal plane, the peak adduction values were higher in the tennis serve, while peak abduction values were lower in the baseball pitch. Peak internal rotation was higher during a baseball pitch, while the tennis serve reached a greater peak external rotation than in baseball. In the frontal plane, the baseball pitch had a greater maximum displacement. The tennis serve exhibits greater range of motion concerning the movements of internal and external rotation within the transverse plane. This information suggests that, with regard to the abduction/adduction motion, the baseball pitch

is characterized by a greater range of motion. Specific values for shoulder position can be seen in Table 3, and are depicted in Figures 6, 7, 8, 9, 10 and 11.

Table 3

Peak Shoulder Angular Positions (°)

	Sagittal Plane		Frontal Plane		Transverse Plane	
	Tennis	Baseball	Tennis	Baseball	Tennis	Baseball
Maximum Displacement	357.42	N/A	78.43	90.43	322.23	128.92
Peak Flexion	179.33	N/A				
Peak Extension	-178.09	N/A				
Peak Abduction			-74.68	-145.76		
Peak Adduction			3.75	-55.33		
Peak Internal Rotation					152.77	57.93
Peak External Rotation					-169.46	-69.28
Peak Horizontal Adduction					N/A	-94.16
Peak Horizontal Abduction					N/A	28.93

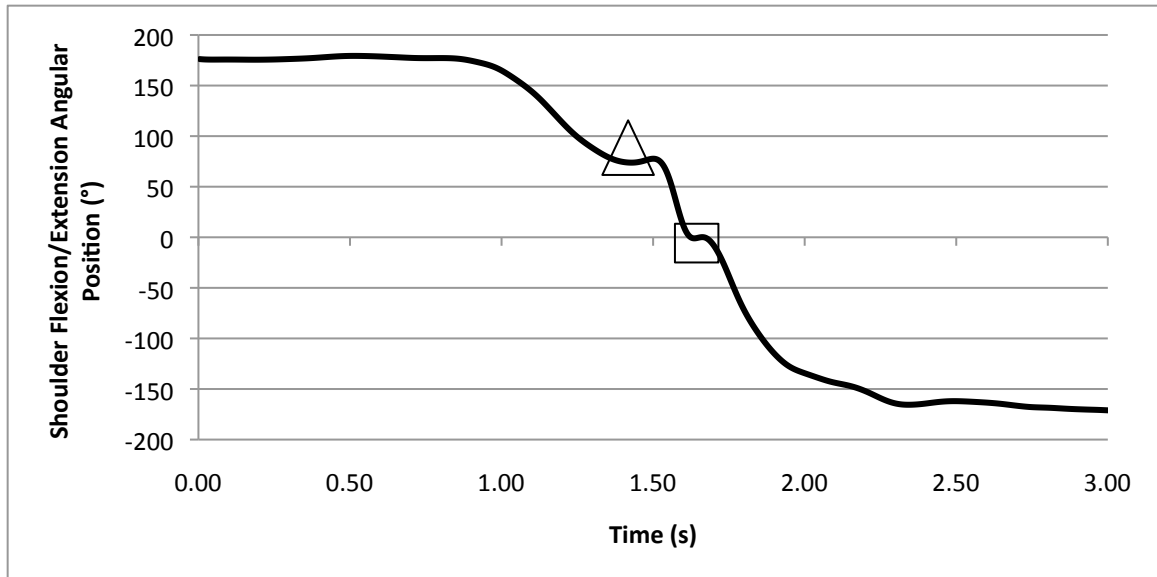


Figure 6. This graph compares the amount of shoulder flexion and extension that occurs during a first serve in tennis. The triangle represents the beginning of the acceleration phase, while the square marks the end of the end of the acceleration phase. The negative trend seen in the graph depicts shoulder extension. During the tennis serve, the shoulder begins in a flexed position. Throughout the phases, the shoulder is brought into extension. Sagittal plane data could not be quantified during the baseball pitch because of the Euler sequence of rotations that was needed to process the specific motion. Therefore, horizontal adduction and abduction were examined at the shoulder during the baseball pitch.

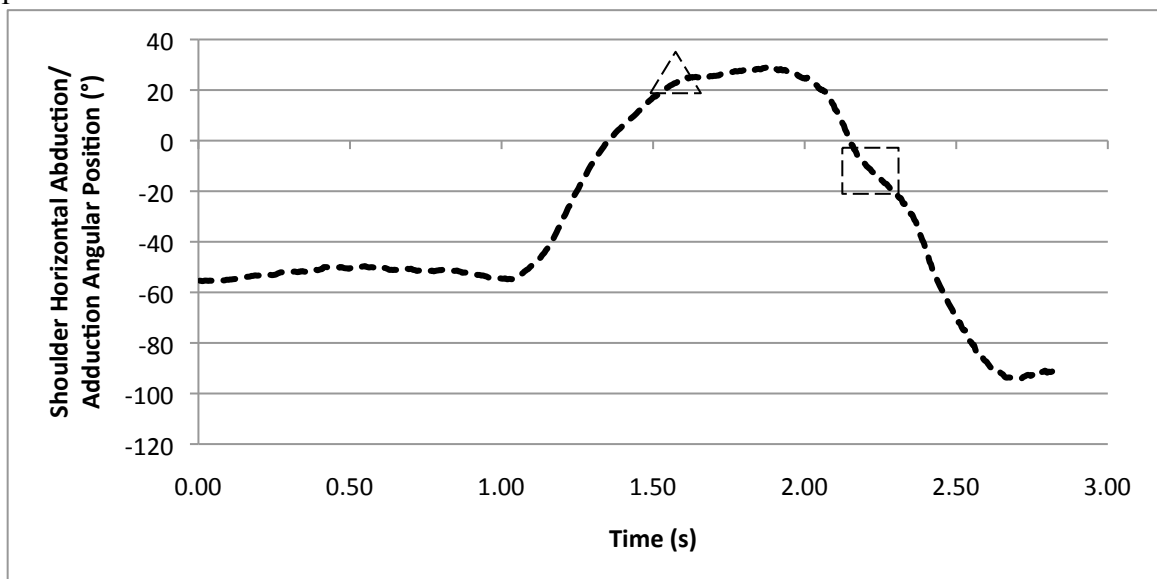


Figure 7. The graph depicts the motion of horizontal adduction and abduction that occurs at the shoulder during the baseball pitch. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. The shoulder begins in a horizontally abducted position then increases in horizontal abduction during the cocking phase and increases into horizontal adduction during the acceleration phase of the pitch.

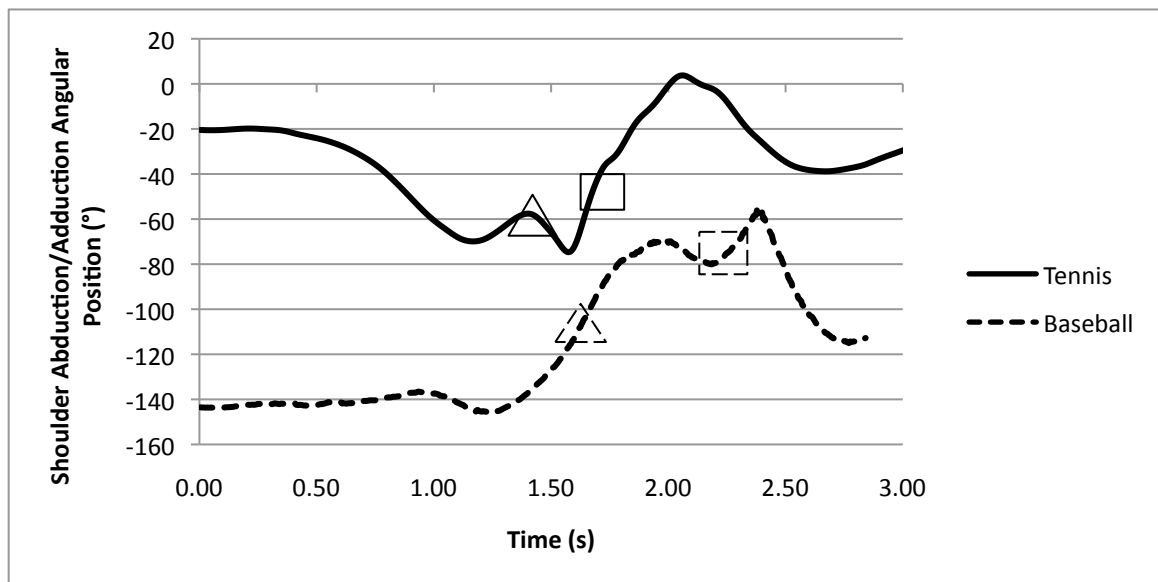


Figure 8. Shoulder abduction/adduction angular position during the two motions is graphed above. The two graphs have different initial starting positions and this could be due to the differences in the motions or due to the different sequences used. The Euler sequence does not relate to anatomical positions like the Cardan sequences do. The negative slope indicates an adduction movement and a positive slope indicates an abduction movement by the athlete. A decrease in overall angular position indicates shoulder abduction, while an increase in angular position closer to 0° demonstrates shoulder adduction. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. For the tennis serve, the shoulder begins in a slightly abducted position during the wind-up phase. In the cocking phase, the shoulder is moved into an abducted position before being rapidly returned to the adducted position during the acceleration phase. The baseball pitch begins in an abducted position and then rapidly adducts. The seemingly different reference points of the two motions are because of the different starting positions, as well as the differences between the Cardan and Euler analyses required for the two sports.

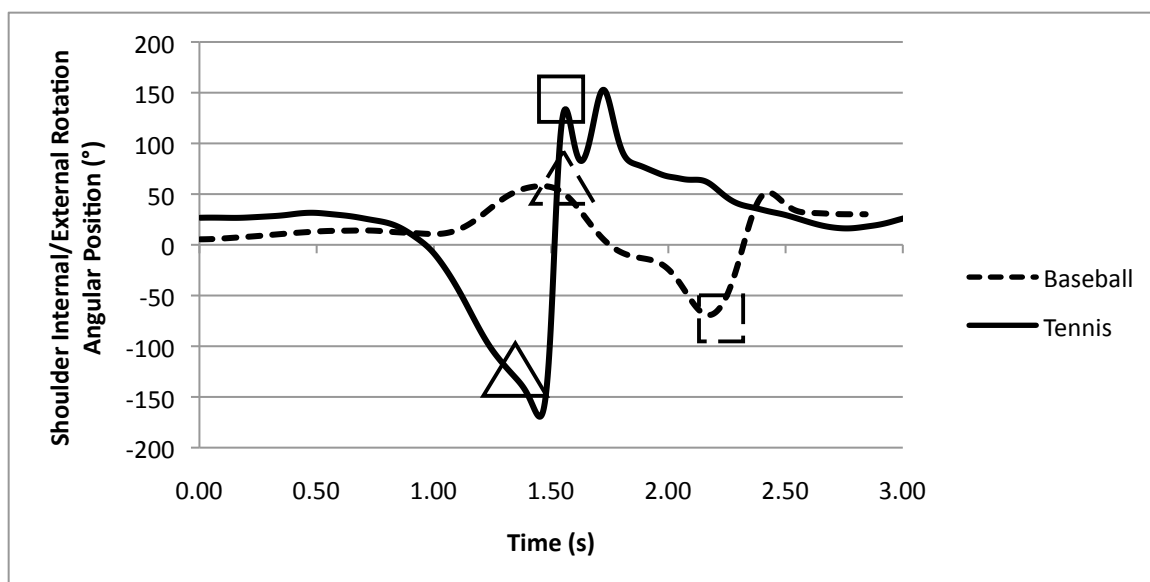


Figure 9. The graph examines the motion of shoulder internal and external rotation angular position during a baseball pitch as well as tennis serve. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. During a tennis serve, the shoulder first experiences external rotation during the wind-up, followed by a rapid internal rotation during the acceleration phase. The baseball pitch starts with slight internal rotation in the wind-up phase, followed by the shoulder experiencing external rotation through the cocking phase. Rapid internal rotation is seen during the acceleration phase of the baseball pitch.

Summary. Lee (1995) claimed, “There are subtle differences between the serving mechanism in tennis and the throwing action of pitching.” The position of the elbow and shoulder within the sports seem similar, which concurs with Lee’s statement. However, because there was no statistical analysis conducted in the present study, a conclusive difference cannot be determined from this study.

Angular Velocity. Angular velocity calculations for the elbow joint include: flexion, extension, adduction, abduction, pronation and supination. In the shoulder, horizontal abduction and adduction, abduction, adduction, internal rotation and external rotation angular velocity occur. Horizontal abduction and adduction calculations were made at the shoulder instead of flexion and extension due to the requirements that the ZYZ Euler angles be used for the analysis of the shoulder for the baseball condition.

Elbow. Peak flexion angular velocity was higher in a first serve in tennis than a fast pitch in baseball. The peak extension angular velocity was also greater in the tennis serve than baseball. Peak abduction and peak adduction angular velocity values were greater in the tennis serve than the baseball pitch. Peak supination and pronation angular velocity values were also greater in the tennis serve than the baseball pitch. It can be suggested that the elbow undergoes a greater angular velocity during a first serve in tennis than a fast pitch in baseball. Velocity graphs comparing angular velocity in the baseball pitch and tennis serve occurring at the elbow joint are presented in Figures 12, 13 and 14 with specific values shown in Table 4.

Table 4

Peak Elbow Angular Velocity Values ($^{\circ}/s$)

	Sagittal Plane		Frontal Plane		Transverse Plane	
	Tennis	Baseball	Tennis	Baseball	Tennis	Baseball
Peak Flexion	355.33	288.92				
Peak Extension	-982.33	-454.89				
Peak Abduction			318.27	232.94		
Peak Adduction			-614.81	-79.92		
Peak Supination					758.76	290.57
Peak Pronation					-225.75	-130.45

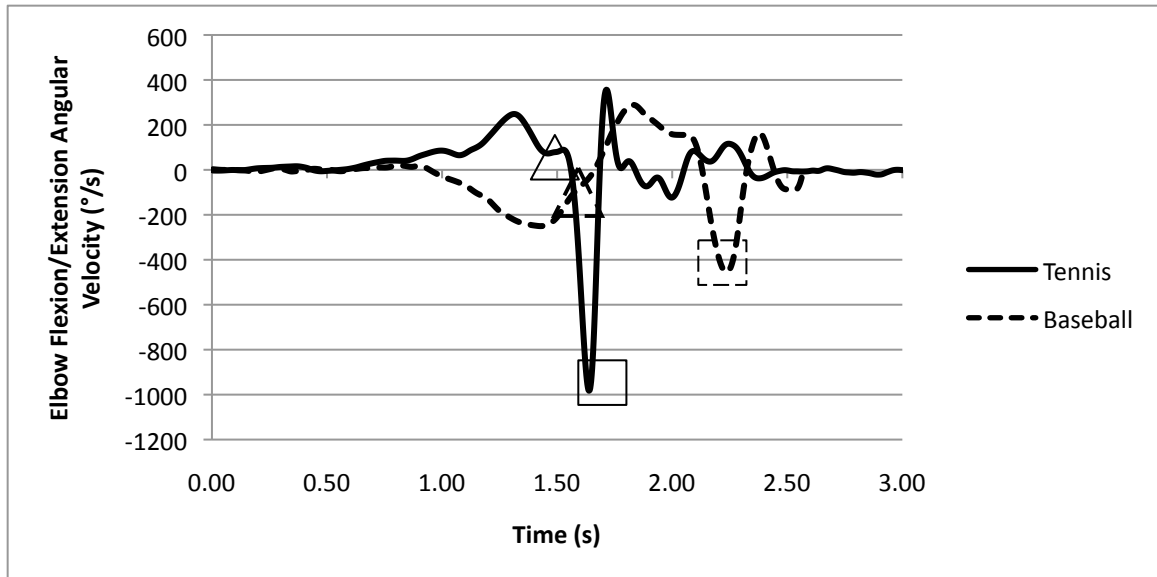


Figure 10. Elbow flexion and extension angular velocity between tennis and baseball motions can be analyzed in the graph above. A positive value represents an extension velocity, seen in the wind-up stage. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase. The tennis serve experiences a larger angular velocity into extension than the baseball pitch. This could potentially be due to the shorter period of time in which the extension motion occurs.

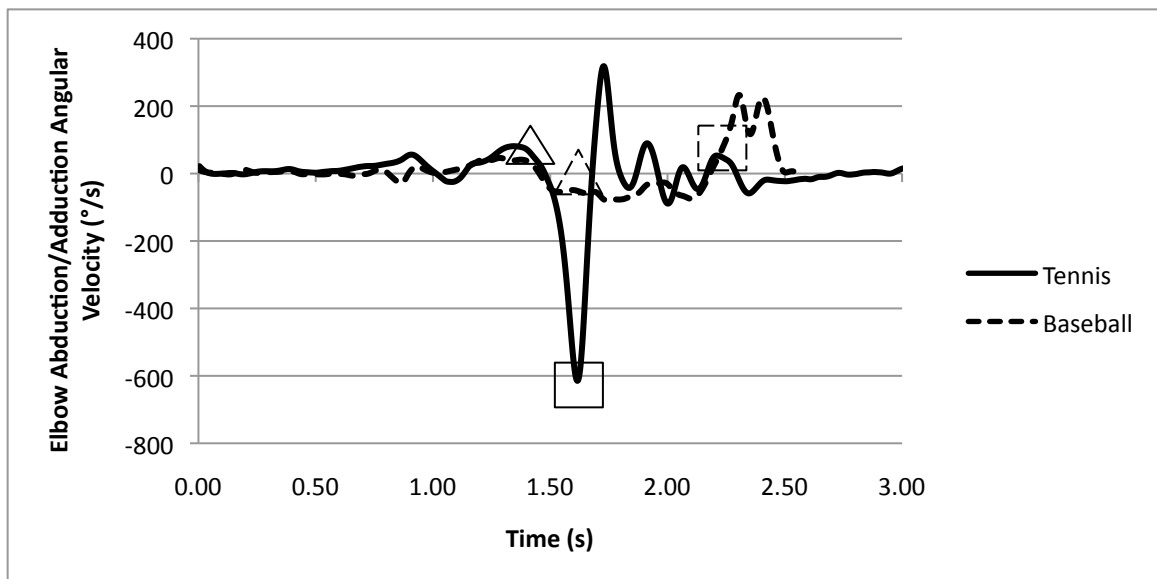


Figure 11. The graph above depicts elbow abduction and adduction angular velocity. The tennis elbow undergoes a rapid abduction motion during the tennis serve. This occurs in the acceleration phase of the serve. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase.

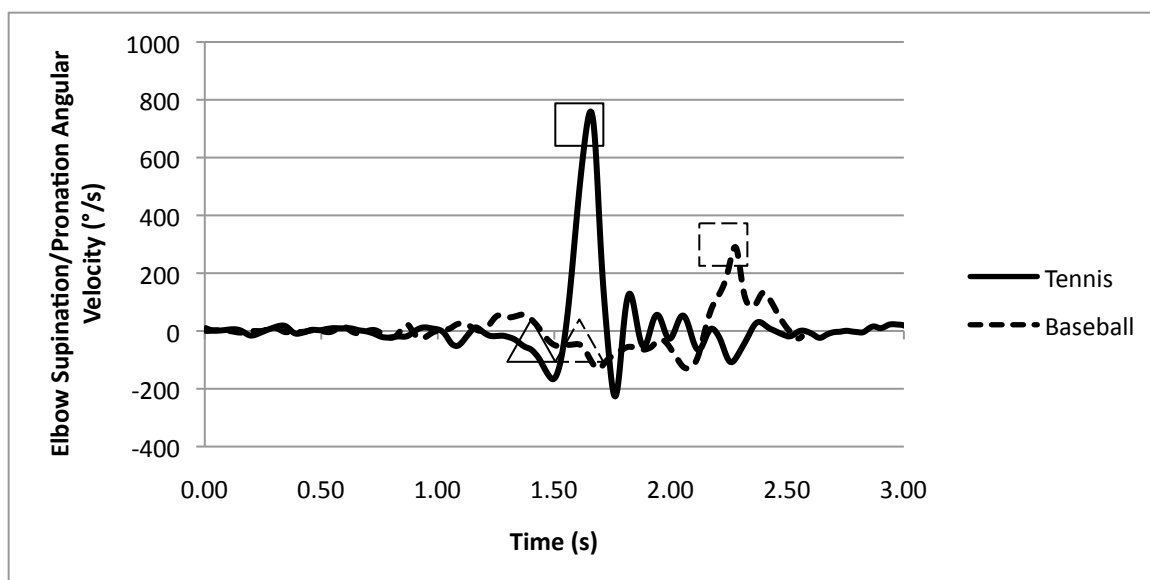


Figure 12. Elbow supination and pronation angular velocity is examined through the graph above. As illustrated by the graph, the tennis serve produces a higher elbow angular velocity into supination than the baseball pitch during the acceleration phase. The triangle represents the beginning of the acceleration phase, while the square marks the end of the acceleration phase.

Shoulder. With regard to the frontal plane, tennis had a higher peak adduction angular velocity value. Baseball, however, had a greater peak abduction angular velocity value. In the transverse plane, tennis had greater peak internal and external rotation angular velocity values than baseball. When comparing maximum displacement in the frontal and transverse planes, tennis exhibited greater angular velocity values. Therefore, with regard to these results, a first serve in tennis creates an overall greater angular velocity at the shoulder than a fast pitch in baseball. Angular velocity values can be seen in Table 5, while graphs of shoulder angular velocity can be seen in Figures 15-20.

Table 5

Peak Shoulder Angular Velocity Values ($^{\circ}/s$)

	Sagittal Plane		Frontal Plane		Transverse Plane	
	Tennis	Baseball	Tennis	Baseball	Tennis	Baseball
Peak Flexion	444.52	N/A				
Peak Extension	-186.66	N/A				
Peak Adduction			491.34	-56.96		
Peak Abduction			-116.66	-145.66		
Peak Internal Rotation					1304.97	57.93
Peak External Rotation					-622.83	-69.28
Peak Horizontal Adduction					N/A	210.06
Peak Horizontal Abduction					N/A	-94.05

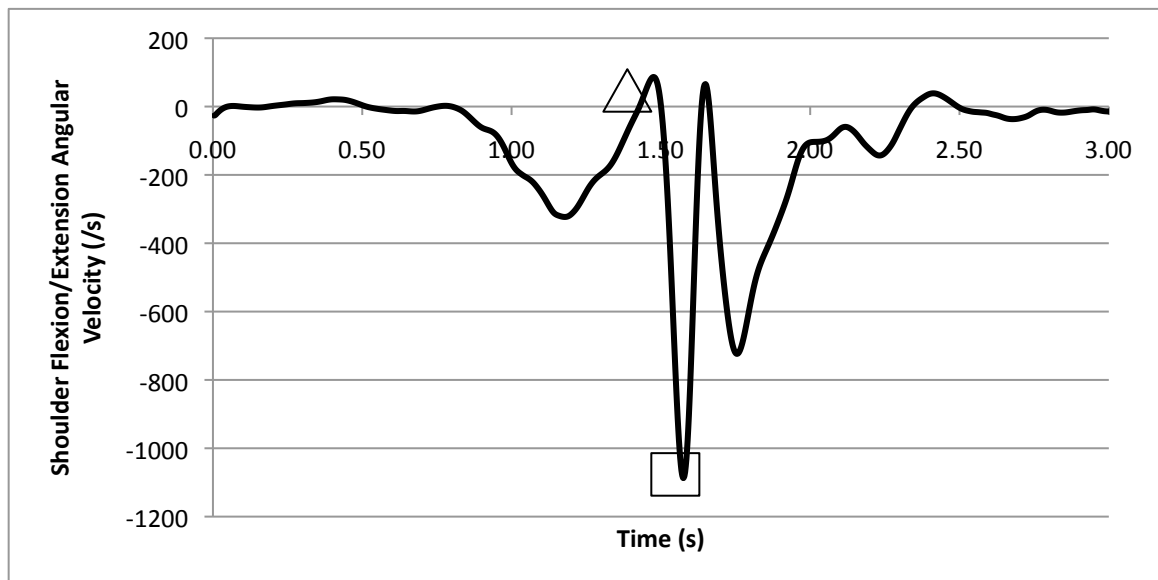


Figure 13. The graph examines angular velocity with respect to shoulder flexion and extension that takes place during a first serve in tennis. The shoulder experiences a rapid shoulder flexion angular velocity during the wind-up phase of the motion. It then has a quick transition into shoulder extension during the acceleration phase, where it reaches maximum shoulder extension velocity that is marked by the square. The acceleration phase is marked on the graph with a triangle showing the start of the phase and the triangle making the end of the acceleration phase. This sagittal plane motion was not available for review during the baseball pitch.

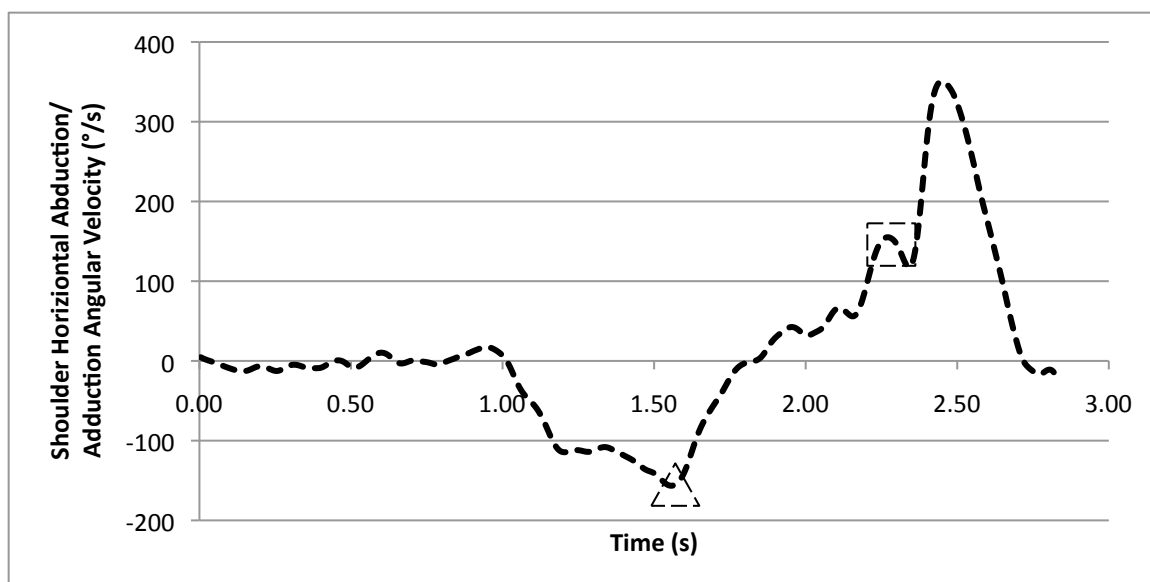


Figure 14. Horizontal adduction and abduction angular velocity at the shoulder during a baseball pitch is graphed above. The positive values on the graph depict horizontal adduction velocity with the triangle representing the peak horizontal adduction velocity. The negative values represent horizontal abduction velocity. The triangle represents the beginning of the acceleration phase and the square represents the end of the acceleration phase. This transverse plane motion was not available for review during the tennis serve.

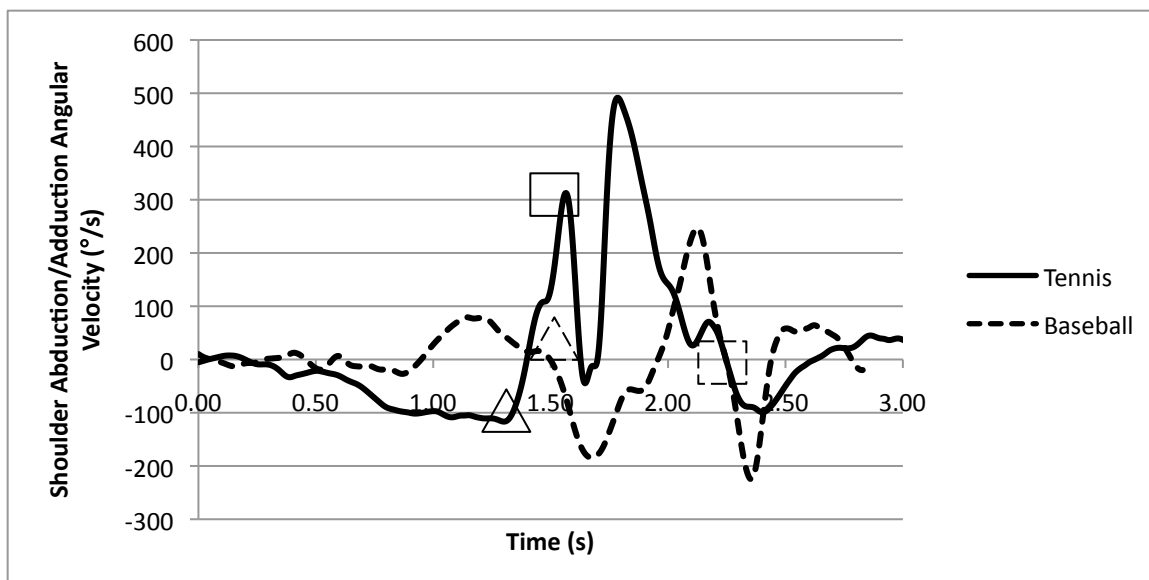


Figure 15. The graph above examines shoulder abduction and adduction angular velocity in a first serve in tennis and baseball. During tennis, the shoulder begins in a slightly abducted position, then rapidly moves into adduction during the acceleration phase, which is marked by the triangle, beginning, and square, the end. The positive values in the graph represent shoulder adduction velocity and the downward, negative values represent shoulder abduction velocity during a tennis serve. During a baseball pitch, the acceleration phase, marked with a triangle, starts with a negative value, which represents shoulder abduction angular velocity. The shoulder then experiences a positive velocity, which represents shoulder adduction angular velocity. The end of the acceleration phase is again a negative velocity, which is shoulder abduction angular velocity.

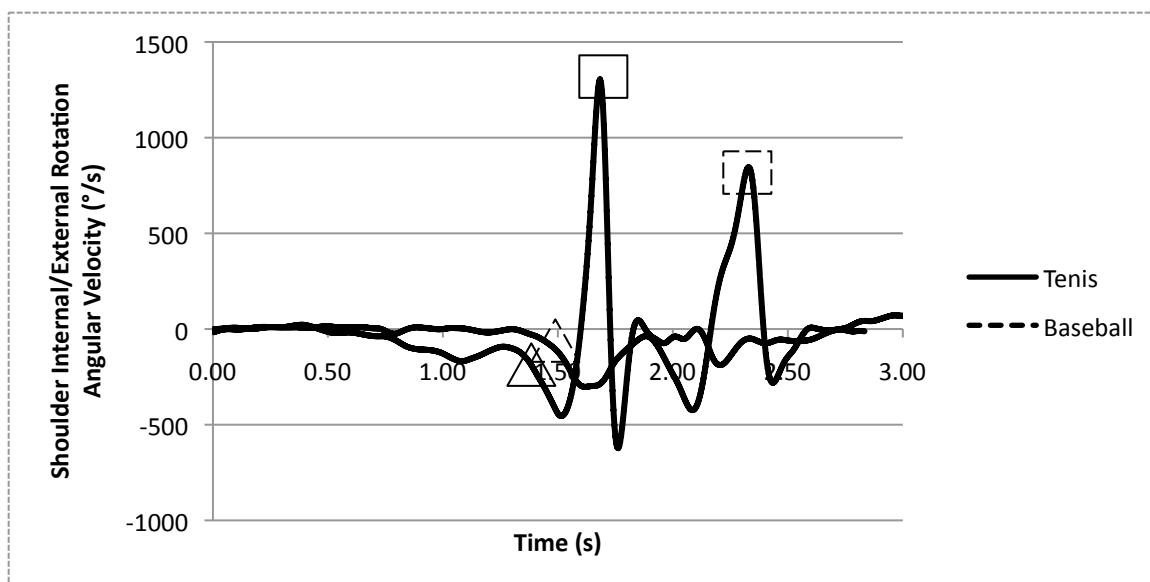


Figure 16. The graph above allows for the examination of shoulder internal and external rotation angular velocity during a first serve in tennis as well as a baseball pitch. The tennis serve undergoes a rapid internal rotation angular velocity during the acceleration phase. This is followed by external rotation during the follow through. During the acceleration phase of a baseball pitch, the shoulder experiences a quick internal rotation velocity ending just prior to the initiation of the follow through phase.

Discussion

While there are very few studies that directly compare tennis and baseball, there is research that has examined some of the same variables as the current study. Several studies examined baseball pitchers (Fleisig et al., 1999; Ishida, Murata, & Hirano, 2006; Murray, Cook, Werner, Schlegel, & Hawkins, 2001; Osbahr et al., 2002; Reinold, Wilk, Macrina, Sheheane, Dun, Fleisig, Crenshaw, & Andrews 2008; Werner et al., 2001; Werner et al., 2002; Werner et al., 2008) while one study looked at tennis athletes (Fleisig et al., 2003). Three tables (Tables 6, 7, and 8) review the current study's findings against previous research.

Werner (2002) and Werner (2001) used professional baseball pitchers and collected data in game situations during Major League Baseball Spring Training in their studies. Two cameras were placed in the left and right field bleachers, while the third camera was

positioned behind and above home plate. Werner (2008) examined 54 collegiate baseball pitchers in a laboratory setting using six electronically synchronized high-speed cameras. Fleisig et al. (2003) used two electronically synchronized 200 Hz video cameras to record 20 tennis players during the Sydney 2000 Olympic games. Murray et al. (2001) collected data from more than 75 professional pitchers during Major League Baseball Spring Training camp. Data was collected using three high speed cameras, one placed behind and above home plate, and the remaining two on first and third base lines, respectively (Murray et al., 2001). Osbahr et al. (2002) examined 19 college male athletes in a lab using a goniometer to take measurements. Reinold et al. (2008) took sixty-seven professional baseball and examined their passive shoulder external and internal rotation, as well as elbow flexion and extension using a plastic goniometer. Ishida et al., (2009) examined 44 young Japanese club baseball players. Athletes were asked to throw a baseball at a target, at which time two high-speed cameras captured the athletes' pitches (Ishida et al., 2009).

Table 6

Shoulder Angular Peak Position Comparison Across Various Studies (°)

	External Rotation	Internal Rotation	Horizontal Adduction	Abduction
Current Study*,+	*109.08 +169.46	*57.93 +152.77	*28.93	*145.76 +74.68
Fleisig (2003)+	172 ± 12		7 ± 9	101 ± 13
Murray (2001)*	181			
Osbaahr (2002)*,x	126.8 ± 12	79.3 ± 13.3		
Reinold (2008)*,x	135.5 ± 9.3	44.6 ± 11.9		
Werner (2001)*	184 ± 14		14 ± 9	
Werner (2002)*				190 ± 33
Werner (2008)*	157 ± 10			

* denotes baseball, + denotes tennis, x denotes PROM at 90° of abduction

Table 7

Elbow Angular Peak Position Comparison Across Various Studies (°)

	Flexion	Extension
Current Study *,+	*122.44 +132.15	*25.01 +32.78
Fleisig (2003)+	104 ± 12	
Reinold (2008)*,x	144.7 ± 5.9	-8.3 ± 8.8

*denotes baseball, + denotes tennis, x denotes PROM

Table 8

Angular Velocity Comparison Across Various Studies (°/s)

	Elbow Extension	Shoulder Internal Rotation	Shoulder Horizontal Adduction
Current Study*,+	+982.33 *454.89	+1304.97 *57.93	*810.06
Fleisig (2003)+	1510 ± 310	2420 ± 590	
Fleisig (1999)*	2320 ± 300	7240 ± 1090	
Ishida (2006)*	1910 ± 310	5500 ± 1680	
Werner (2001)*	2500 ± 513		
Werner (2002)*			933 ± 33
Werner (2008)*	2251 ± 465		

*denotes baseball, + denotes tennis

The peak shoulder angular position (Table 6) exhibits similar values as other studies, although lower in some situations. Fleisig et al. (2003), who also studied the tennis serve, recorded external rotation of $172 \pm 12^\circ$, while the current study fits in the mean with a peak external rotation of 169.46° . However, the same study found $101 \pm 13^\circ$ of peak shoulder abduction, while the current study had a lower value of 74.68° . Looking at the baseball results, the current study has lower results than other studies in angular peak external rotation (109.08° and $137.3 \pm 18.3^\circ$ (Mullaney et al., 2005), 181° (Murray et al., 2001), $126.8 \pm 12^\circ$ (Osahr et al., 2002), $184 \pm 14^\circ$ (Werner, 2001), $157 \pm 10^\circ$ (Werner, 2008), $135.5 \pm 9.3^\circ$ (Reinold et al., 2008), respectively). When comparing peak internal rotation, the current study compares well with a range of motion with studies that measured internal rotation passively. The current study had a peak internal rotation of 57.93° , while two of the lab studies had values of $63.5 \pm 8.7^\circ$ (Mullaney et al., 2005) and $44.6 \pm 11.9^\circ$ (Reinold et al., 2008). Osahr et al. (2002) collected data passively ($79.3 \pm 13.3^\circ$) and reported internal rotation higher than the current study. Peak horizontal adduction position for baseball was 28.93° in the current study. Only one other study measured horizontal adduction (Werner et al., 2001) and was lower than the current study at $14 \pm 9^\circ$. Peak shoulder abduction position was measured by Werner (2002), and recorded a higher value than the current study ($190 \pm 33^\circ$ and 145.76° , respectively).

Angular peak positions in the elbow (Table 7) were recorded by a study focusing in tennis (Fleisig et al., 2003) and a study that examined baseball (Reinold et al., 2008). The elbow motion in the baseball athlete was lower in the current study during flexion than from Reinold et al. (2008), 122.44° and $144.7 \pm 5.9^\circ$, respectively. However, extension in the

current study was a higher value, 25.01° , than Reinold et al. (2008) of $-8.3 \pm 8.8^\circ$. The negative value from the study represents hyperextension.

Angular velocity in the shoulder and elbow (Table 8) were reviewed for specific motions. The tennis actions of elbow extension and shoulder internal rotation recorded in the current study were lower than the values recorded by Fleisig et al. (2003). Fleisig et al. (2003) recorded elbow extension angular velocity of $1510 \pm 310^\circ$, while the current study had an angular velocity of 982.33° . Shoulder internal rotation angular velocity recorded by Fleisig et al. (2003) was $2420 \pm 590^\circ$, and the current study had a level of 1304.97° . The levels of elbow extension angular velocity and shoulder internal rotation angular velocity were much lower in the current study ($454.89^\circ/\text{s}$ and $57.93^\circ/\text{s}$, respectively) than other studies ($2320 \pm 300^\circ/\text{s}$ and $7240 \pm 1090^\circ/\text{s}$, Fleisig et al. (1999), $1910 \pm 310^\circ/\text{s}$ and $5500 \pm 1680^\circ/\text{s}$, Ishida et al. (2006), elbow extension angular velocity and shoulder internal rotation angular velocity, respectively). Elbow extension was also reviewed by Werner (2001) and Werner (2008), $2500 \pm 513^\circ/\text{s}$ and $2251 \pm 465^\circ/\text{s}$, respectively. Werner (2002) also investigated shoulder horizontal adduction angular velocity and recorded a measure of $933 \pm 33^\circ/\text{s}$, where the current study had a lower shoulder horizontal adduction of $810.06^\circ/\text{s}$.

Differences seen between studies are likely due to the experience of the athlete and the alteration to the motion during the data collection. The fact that the subject was not able to actually throw a baseball or hit a tennis ball may influence his performance, including the velocity of his arm. While the subject for the current study had several years of tennis and baseball familiarity, he did not have the same training professional and collegiate athletes undergo throughout their career. This lack of first-hand experience in a more competitive setting could affect the results for angular velocity. However, the years that the subject did

compete in the two sports provided him with knowledge base for proper technique in angular positioning, making these results more likely than in a novice population to be an accurate portrayal of the movements compared to those who have less experience, despite the use of a tennis ball or baseball.

Summary

The two sports were similar in their overhead motions with regard to shoulder and elbow position. The elbow showed similar amounts of flexion and extension in both sports. While the maximum displacement was similar in the frontal plane, for abduction and adduction, the angular positions are largely different in the elbow. Elbow supination and pronation had very different maximum displacements as well as angular positions, although there wasn't a trend in one sport having a greater ROM in that plane. The shoulder positions have a different maximum displacement between tennis and baseball, as well as the shoulder positions. Overall, the elbow angular velocity values for this study were not similar between the two sports, generally the tennis serve had larger values. The tennis serve tended to have higher angular velocity values in the shoulder than the baseball pitch when the two motions could be compared. Because there was no statistical analysis conducted, significant difference cannot be evaluated. However, angular velocities at the shoulder and elbow are visibly different and warrant further examination.

Chapter V

Summary and Conclusions

Summary

Tennis and baseball are popular sports. Both sports require similar overhand motions, but result in two different variable outcomes. Tennis serves have been measured at high speeds of 150 miles per hour, while baseball can be seen at 104 miles per hour. Although both sports yield high velocities and a similar motion, reports of injuries are in different sections of the body (i.e., tennis athletes report lateral epicondylitis while baseball pitchers report medial epicondylitis). Despite several studies performed within each sport (Dun et al., 2008; Elliott et al., 2003; Gordon & Dapena, 2006; Werner et al., 2001; Werner et al., 2002; Werner et al., 2008), it is rare to see research that compares the two motions.

The subject of this study consisted of one healthy man from Western Washington University. The subject met with the researcher for thirty minutes for two sessions. He was asked to warm-up at a self-determined rate until he was able to perform a normal throwing or serving motion. Markers were placed on the participant by the same researcher in a manner described in Appendix C. Similar protocol for warm-up and marker placement is observed in previous research (Dillman et al., 1993; Dun et al., 2008; Fleisig et al., 1995; Fleisig et al., 1999; Fleisig et al., 2006; Stodden et al., 2005). Visual 3-D software was used to examine and extract data from the each of the subject's motions.

Overall, the biggest differences seen between the current study and other studies that examined overhead motion are in the angular velocity movements of the elbow and shoulder. The other studies have much higher angular velocities than the current study. This is not surprising, as the subject of the current study was not a professional athlete, whereas a

majority of the other subjects were high-level athletes. The subject of the current study was a college athlete and partakes in regular physical activity, including competitive javelin throwing, which may account for the more similar peak positions between the current study and other studies.

When comparing the two sports within the study, the greatest differences were seen in the angular velocity at both the shoulder and elbow. The tennis serve reached higher velocities at both body parts than the baseball pitch. This difference likely accounts for the higher ball velocity seen in tennis. When examining the risk for injury, specifically medial epicondylitis, the current study is not useful to explain the difference between the two sports. Elbow varus stress is comprised of four motions: elbow abduction, elbow flexion, shoulder external rotation, and shoulder horizontal adduction. Elbow abduction was greater in the baseball pitch. However, two of the other variables, shoulder external rotation and elbow flexion, are higher, however slightly, in the tennis serve. Unfortunately, there is no way to compare horizontal adduction between the two sports, as there was no value collected for tennis. The data gathered in the current study does not suggest that participants in one sport should be at greater risk than the other for medial epicondylitis, however this study did not gather sufficient measurements to make an accurate portrayal of the risk.

Conclusions

There are several potential reasons for the differences seen between the current study and previous research. One is the level of play between studies. While the current study did utilize a college-aged subject, his lower caliber of experience is different than other research. The experience could influence how much overall velocity the subject is able to produce, thereby accounting for the lower values seen in the current study. The difference in age and

level of play between the current and previous studies may account for the current study finding lower velocities as it has been suggested that kinematic differences are likely due to greater muscle strength (Fleisig et al., 1999). Another possible explanation is the situation in which data was collected. Previous research was gathered during competition (Elliott et al., 2003; Fleisig et al., 2003; Sabick et al., 2004; Werner et al., 2001) or in an area where subjects could use a ball to perform the respective tasks (Elliott et al., 2003; Fleisig et al., 1996; Fleisig et al., 2006; Gordon & Dapena, 2006; Stodden et al., 2005; Werner et al., 2008). This is much different than the current study, which required a subject to go through the motions of their sport in the lab without a ball to throw or hit.

Variables such as joint position and angular velocity have a direct effect on the risk of injury to athletes. Previous studies suggest that a greater amount of injury is seen with an increased range of motion as well as high velocities. It is undetermined, however, if it is the increased range of motion or the increased angular velocity that causes this threat. The current study shows the angular positioning was similar between the two sports, but the angular velocity was different, in favor of the tennis serve creating greater values. This would suggest that tennis athletes are at greater risk for injury than baseball pitchers, which contradicts previous research. By comparing the angular velocity values of the baseball pitch in the current study with other research, it is noticed that the values are lower than a professional athlete, creating an accurate comparison of the results difficult. A lack of research on the variables of this study in tennis athletes also makes verifying the angular velocity results for the tennis player impossible. Therefore, it is difficult to conclude that the tennis player is at greater risk for injury than a baseball pitcher.

Based on the findings of this study, angular positioning is similar at the elbow, but different with regard to the motions of internal and external rotation at the shoulder in the sports of tennis and baseball. The graphs of the study seem to suggest that the largest difference of the sports lay in the angular velocity at both the shoulder and elbow. However, the angular velocity results of the current study are lower than the results found in previous research. Therefore, further research with regard to the forces and torques at the shoulder and elbow need to be performed to create a more accurate portrayal of the specific population and their risk of injury.

Recommendations

The following recommendations are suggested for further investigations:

1. Capturing pitches and serves during game situations may allow the results to be directly applicable to these sports.
2. The athlete felt restriction from the segment marker sleeves. Adjusting the marker setup may create a more accurate trial of motion.
3. Certain trials were difficult to capture because of the height of the athlete as well as the speed at which he performed the task. This could possibly be reduced by utilizing a different type of capturing method.
4. A long-term study could be performed to see if different pitching styles (e.g. slider vs. curve ball) significantly relate to injury rate.
5. Different results might occur with either a more experienced or higher level population.
6. By having a larger subject population, a stronger relationship may potentially result.

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Appendix A
Informed Consent

Informed Consent

Volunteer copy / Investigator copy

An equal opportunity university

Department of Physical Education, Health &
Recreation

516 High Street, Bellingham, Washington
98225-9067

(360) 650-3105 Fax (360) 650-7447

INFORMED CONSENT FORM
WESTERN WASHINGTON UNIVERSITY

Title of Investigation: Upper extremity biomechanical differences between a pitch and a tennis serve.

Investigator: Marc Keller
Department of Physical Education, Health and Recreation
516 High St.
Western Washington University
Bellingham, WA 98225-9067
Phone: (360) 650 – 3449 or (360) 303-2078
kellerm4@students.wvu.edu

This is to certify that I, _____,
hereby agree to participate as a volunteer in a scientific investigation as an authorized part of
the education and research program of Western Washington University under the
supervision of graduate student Marc Keller.

Purpose of the Study:

The study in which I will be participating is designed to explore the relationship between
linear and angular displacements and velocities of the elbow and the shoulder to determine
what differences, if any, exist between the two overhand upper extremity motions.

Procedures to be followed:

I understand that males and females between the ages of 18 to 30 will be invited to
participate in this study. I understand that in order to participate in this study:

- I must be over the age of 18 years,
- I must be free of injury to the muscles, bones, or joints of the upper and lower extremity,
- I must have full range of motion of my trunk, shoulder, elbow, wrists, hips, knees, and ankles,
- I must have experience in baseball pitching or tennis

I understand that the study will require attendance at one session (totaling ~1.5 hours), and that the activities will be as follows:

- I will receive a detailed explanation of the study procedures.
- I will read and sign the informed consent form.
- My age, height and weight measurements will be recorded.
- I will perform a 5 minute warm up and have 24 reflective markers placed on my upper body. The markers will be placed either on my skin with hypoallergenic adhesive collars or strapped around a segment with elastic banding.
- Measurements will be taken of my hand, forearm, and upper arm segments, measured from proximal joint marker to distal joint marker with a flexible ruler.
- I will be instructed to stand in the middle of the data collection area and face the direction of the motion I will be performing. I will stand perfectly still while a 3 second standing trial is captured by the seven cameras focused on the center of the measurement area.
- After the standing trial is captured, I understand that the joint markers will be removed and the segment markers will be left on for motion capture. Then I will be instructed to perform either the baseball throw or tennis serve five times. I understand that the best trial will be analyzed. Once I have completed the throw or serve, I understand that the segment markers will be removed.

Discomforts and Risks:

I understand that, as with any exercise program, there are risks of injury due to accidents during the exercise activities. Additionally, I realize that there may be minimal risk, such as discomfort or pain as a result of injury to involved musculature, joints or connective tissue. These are risks associated with any physical activity. If I experience pain, I am aware that I may withdraw from participation in this study at any time, without penalty.

If I feel I cannot or should not perform the pitching or tennis serve movements, I should not participate in this study.

Benefits to Me:

I understand that there are no direct benefits to me as a result of participating in this study, however, the results may help me analyze or identify areas of improvement in my pitch or tennis serve.

Potential Benefits to Society:

By participating in this study I will be contributing to research that aims to advance our understanding of both performance and injury prevention in high velocity upper extremity patterns. The differences in velocities that will be identified in this study may be helpful in accounting for the injury differences between the two sports and could provide pathways for correction to limit injuries within the sport.

Statement of Confidentiality:

I understand that any data or my answers to questions will remain confidential with regard to my identity. Only the investigator and his/her assistants will have access to my identity and to information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed.

The investigation and my part in the investigation have been defined and fully explained to me by Marc Keller or his assistant and I understand his/her explanation. The procedures of this investigation and a description of any risks and discomfort have been discussed in detail with me and I understand that a copy of the signed consent form will be provided to me.

Right to Ask Questions:

I have been given an opportunity to ask whatever questions I may have had and all such questions have been answered to my satisfaction.

I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires. If I have any questions about this study, I can contact Marc Keller at the contact information listed on the front page of this consent form.

I understand that for additional information about my rights as a research participant, I may contact the WWU HSRC Administrator, at:

Janai Symons
 HRSC Administrator
 Research and Sponsored Programs
 Old Main Building 530
 Western Washington University
 Bellingham, WA 98225-9038
 (360) 650-4403
janai.symons@wwu.edu

Event of injury:

I understand that emergency medical care will be summoned in the event of injury resulting from this study. In the event of adverse effects related to this study, I understand that I shall contact the office listed above. I also understand that I am not waiving any rights that I may have against WWU for injury resulting from negligence of the University or investigators.

Voluntary Participation:

I understand that my participation in this study is voluntary, and that I may withdraw from this study at any time by notifying the investigator. I also understand that my participation may be terminated by the investigator if I do not fit any of the pre-determined subject categories or if he or she feels that my personal well-being is in question.

This is to certify that I am over the age of 18 years, and I consent to and give permission for my participation as a volunteer in this program of investigation. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

Volunteer

Date

I, the undersigned, have fully explained the investigation to the above subject.

Investigator

Date

Audiotaping, Videotaping, and Photography

By initialing on the lines below, I am indicating that I give the research team permission to (please initial all that apply):

_____ Photograph, audiotape and/or videotape my participation in this study.

_____ Use photographs, audiotape or videotape recordings of me when they present this research in educational and professional venues, *even if I am personally identifiable*.

_____ Use photographs, audiotape or videotape recordings of me when they present this research in educational and professional venues, *only as long as I am not personally identifiable*.

Appendix B
Health History

Health History

Department of Physical Education, Health, & Recreation
Western Washington University

Health History

NAME: _____ BIRTHDATE: _

ADDRESS: _____ CITY: _____

ZIP: _____

PHONE: _____ AGE: _____ HEIGHT: _____ WEIGHT: _____

1. Do you currently have any injuries or medical conditions? If yes, please list.
2. Are you currently receiving any medical treatment for any condition? Yes or No? (Circle one)

If yes, please explain.
3. Are you currently receiving any physical therapy or chiropractic treatment for any condition? Yes or No? (Circle one)

If yes, please explain.
4. Are you physically active? How often?
5. Is there any other condition not mentioned here that might affect your ability to perform a pitch or tennis serve? Yes or No? (Circle one)

If yes, please describe.
6. What is your experience in baseball/softball or tennis?

Appendix C

Marker Placement and Camera Setup

Marker Placement Photos and Camera Setup

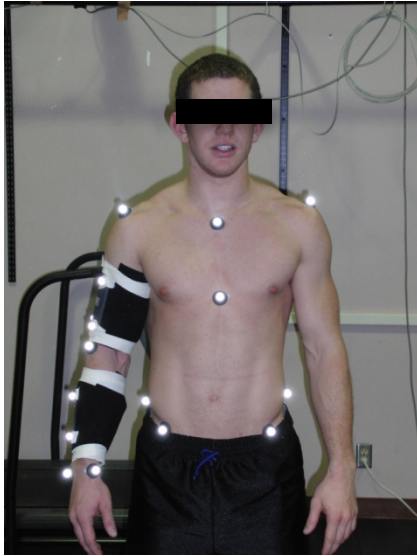


Figure 21. An anterior view of the placement of markers on the subject.

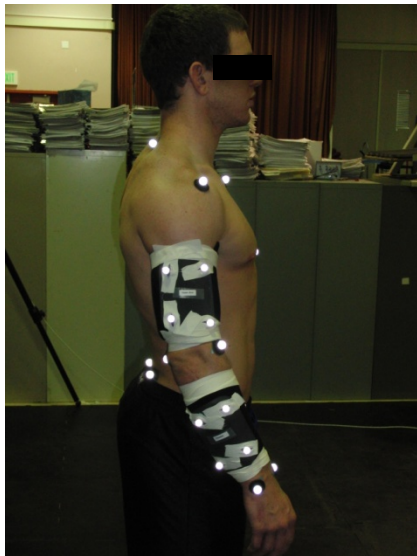


Figure 22. A side view of markers on the subject. Additional tape was needed to hold the arm clusters in place.



Figure 23. Four markers were placed on the posterior aspect of the body.